

ASTRONOMY

Exotic Pulsars

Red Planet Roundup

Galaxies from the Beginning of Time

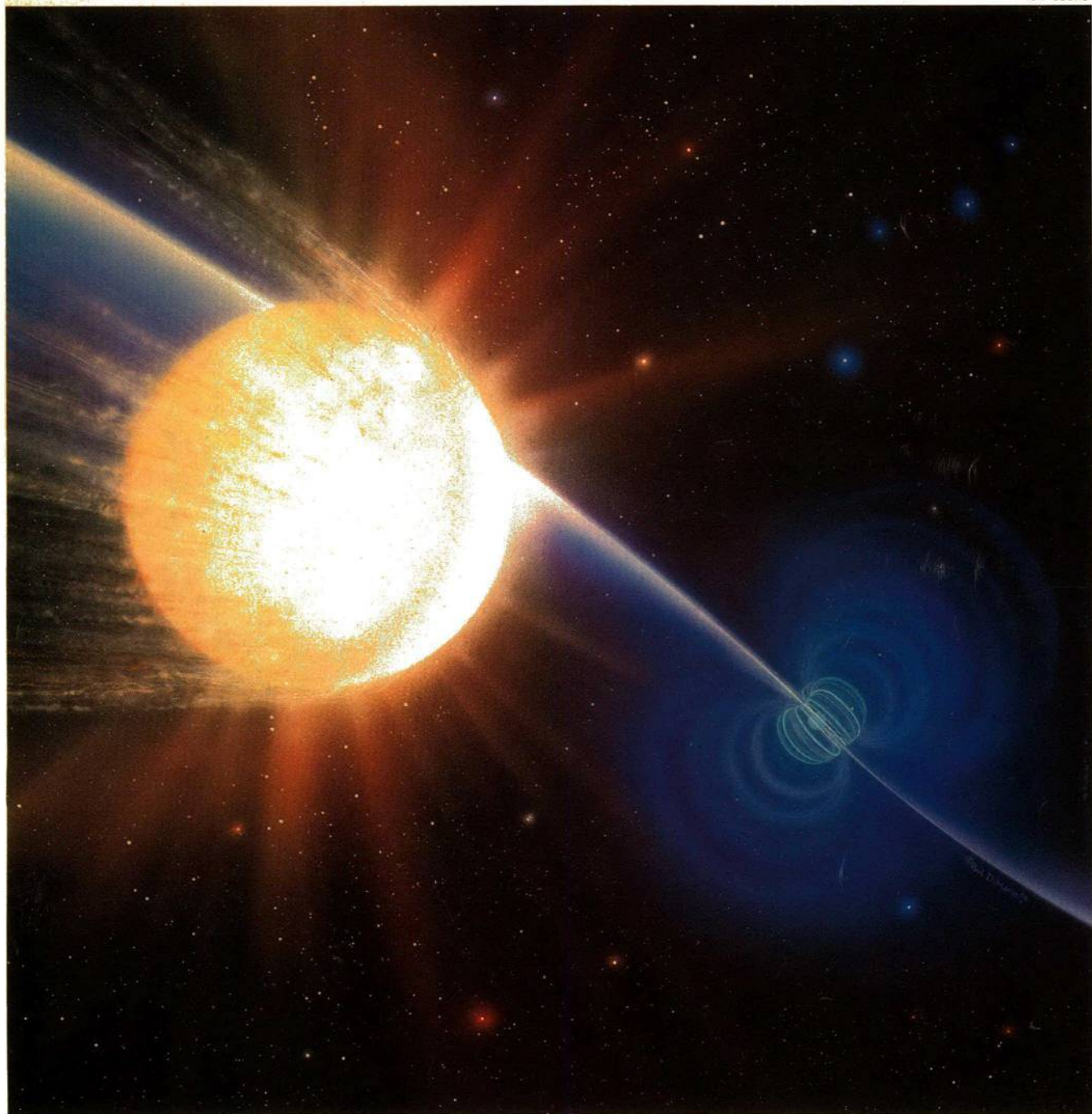
December 1988

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The Pulsar Powerhouse



Meade® Wide-Field f/6.3 SCT's:



For the First Time Ever — Wide-Field Schmidt- Cassegrain Telescopes that Yield a 60% Reduction in Photo Exposure Times!

New Meade 8" and 10" LX6 Wide-Field Schmidt-Cassegrains combine the wide fields of view, fast photo exposure times, and high-contrast imaging long sought by the serious amateur. Consider this listing of *standard* LX6 features:

1 Fast f/6.3 Schmidt-Cassegrain Optics — Optics that yield photographic and visual performance impossible to achieve with the f/10 optics that are standard on all other SC telescopes. Eyepiece for eyepiece, obtain:

☐ A field of view that is **59%** wider than with f/10 Schmidt-Cassegrains. Use the Meade Super Wide Angle 40mm eyepiece on the 8" LX6 to

obtain a true field over 2 degrees in diameter!

☐ Images both visually and photographically that are **2 1/2 times** brighter than with an f/10 system.

☐ A **60%** reduction in astrophoto exposure times: 30 minute exposures become 12 minute exposures. Used with modern fast films, a **5-minute** color exposure of the Orion Nebula (M42) taken with the 10" Model 2120/LX6 yields virtually all of the nebular detail that is theoretically possible to obtain with a 10" telescope! With the optional Meade **Telecompressor Lens**, for an effective focal ratio of f/3.15, this exposure time is reduced still further to about **3 minutes** — an unheard of exposure time for a photo-visual telescope of 10" aperture, an exposure time that means anyone with an absolute minimum of experience can take magnificent deep-space astrophotos!

2 Ultra High Contrast Baffling — In addition to their superlative wide-field deep-space performance, Meade 8" and 10" LX6 models, because of their computer-optimized internal light baffles, yield uncompromised, high-contrast lunar and planetary images. Add the Meade 3-element **#140 2X Telenegative Barlow Lens** to obtain high-power lunar and planetary images at f/12.6.

3 Built-In Digital Readout Capability — One of the most important optional features ever made available on a Schmidt-Cassegrain: now you can find faint objects in seconds, not minutes. The LX6 Digital Readouts, located on the hand controller display, permit continuous monitoring of: (a) telescope position in RA and Dec; (b) Local Time; (c) Sidereal Time; (d) a Digital Timer for photo exposures; and (e) Frequency readout of the pulse motor's input current — a feature that enables extremely precise digital settings of the telescope's drive rate, readable to within ± 0.1 Hz. The observer simply depresses the "Mode" button on the hand controller to read out the listed data sequentially.

The Digital Readout package can be internally added easily and rapidly to the hand controller of your LX6, either at the time of purchase or at any

Meade 8"
Model 2080/LX6



future date, and is available at only modest additional cost.

4 New Multi-Function Electronic Command Center — The ECC hand controller, included as standard equipment, puts virtually every telescope function at your fingertips:

☐ **2X Drive Correction Speed** for precise electronic corrections during astrophotography.

☐ **8X Scanning Speed** for rapid electronic centering of the image in the field, or for roving about a specific sky region at 8 times the sidereal speed. Add the optional Declination motor for full dual-axis capability at 2X or 8X speeds.

☐ **Optional Digital Readouts**, described above.

☐ **Plus 6 other functions** that make Meade LX6's the only state-of-the-art Schmidt-Cassegrains available.

5 Quartz Microprocessor-Controlled Electronic and Drive Systems — The heart of every LX6 electronic system is a dedicated microprocessor that continuously controls, with quartz precision, all important electronic operations of the telescope, from the drive-rate frequency input to the main RA pulse motor, to the Electronic Command Center's multi-function digital readouts.

Augmented by the microprocessor, the RA pulse motor and LX worm gear system achieve true sidereal-rate tracking within $\pm 0.005\%$ of the sidereal frequency, and with greater reliability than ever before. Switch to the "Manual" mode for variable Solar, Lunar, or Planetary tracking rates.

6 Advanced-Design Power Panel — Virtually every modern electronic accessory you might wish to add to your LX6 can be plugged-in directly to the telescope's power panel —

accessories including the Meade **CAT Computer Aided Telescope** system (see our other ad in this issue), with its library of more than 8000 astronomical objects; **Digital Readouts**, readable on the LX6 hand controller (see above); **#1200A Electric Focuser**, for ultraprecise microfocusing; **12mm Illuminated Reticle Eyepiece**, for guiding during astrophotography; and the **Declination Motor**, for 2X/8X dual-axis operation.

In addition, the LX6 power panel includes an **Ammeter**, which continuously displays electric current usage, to gauge battery life during power cell operation; a **North-South Switch**, permitting your LX6 to be used anywhere in the world — simply flip the N-S switch to reverse drive direction for use in the Southern hemisphere; and **12-volts DC Power Inlet**. Each LX6 includes power cords for 3 types of field operation: Directly from auto cigarette lighter plugs; directly from 115v. AC home outlets; and from the Battery Pack, included, using AA-size batteries supplied by the user.

7 Plus all of the features you expect on a top-of-the-line Meade Schmidt-Cassegrain

— *Standard* features that include a **Super Plössl 26mm eyepiece** for exquisite definition and resolution across the entire visual field; 1/10-wave flat, multi-coated **2" Diagonal Mirror** with eyepiece holders for both 1 1/4" and 2" eyepieces; **9 x 60mm Polar Illuminated Viewfinder**, the largest finder available on a commercial SCT; **Multi-Coated Optics Group**, with multi coatings on all lens and mirror surfaces for maximum light transmission and image brightness; **Equatorial Wedge**, with magnetic compass, latitude scale, bubble level, and micrometric azimuth control; and **Variable-Height Field Tripod**, the most stable in the industry.

Priced only slightly higher than conventional f/10 Schmidt-Cassegrains, Meade 8" and 10" LX6 models achieve photographic and visual performance levels unobtainable with any competing telescopes.

Call or visit your Meade dealer now for further details and prompt delivery of the Meade 8" Model 2080/LX6 or 10" Model 2120/LX6 — from the World's leading manufacturer of Schmidt-Cassegrain telescopes.

Bulletin LX6 — Available at no charge, includes complete technical specifications, descriptions, and applications, with astrophotos, of Meade LX6 models.

Complete Catalog Package #88C — \$3.00 — Includes catalogs and bulletins on the entire range of Meade astronomical telescopes, Series 4000 eyepieces, and accessories.

Dealer Locations and Assistance — For your nearest Meade dealer location, or for free telescope information and assistance, call Meade Instruments toll-free from anywhere in the continental U.S.A. (except California): **1-800-854-7485**. From all other areas, including California, call direct (714) 556-2291.



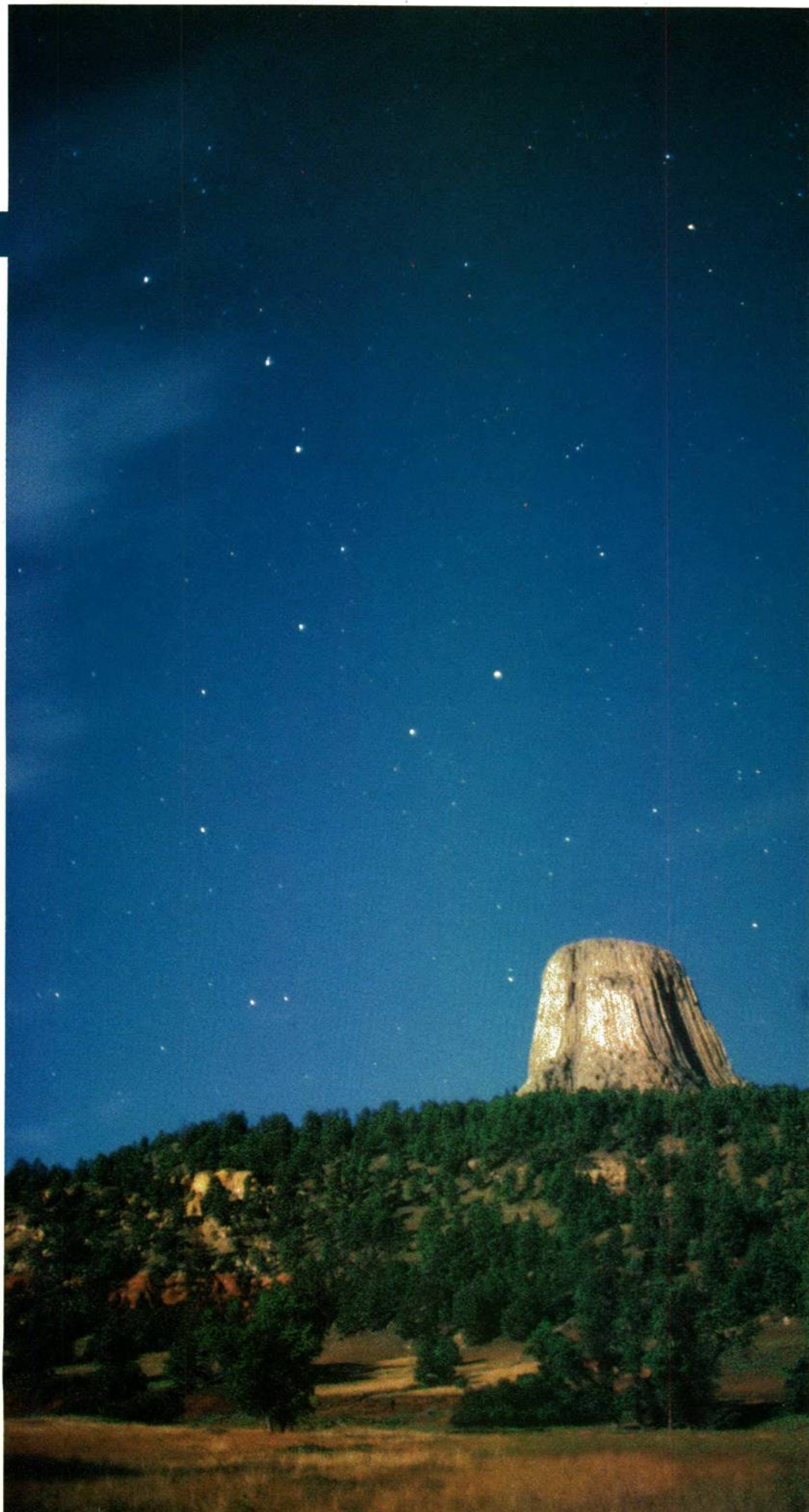
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ON THE COVER:

A millisecond pulsar blasts its white dwarf companion with an unrelenting stream of powerful radiation. Over the course of time the companion will "evaporate."

THE BIG DIPPER sets over Devil's Tower, Wyoming. A 50-second exposure under the Full Moon gives the landscape daylightlike illumination. Photo by Jerry Schad.



ASTRONOMY[®]

December 1988

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MANY WORLDS IN MARS

You couldn't ignore Mars this fall as it blazed in the eastern sky. Its strong color and steady bright light drew the eye in a moment; with a telescope the ruddy ball loomed large. No matter which way you looked at it, Mars captured your mind and imagination.

As I watched Mars move east against the stars, stop, move west, and then resume its eastward travel this year, I was reminded of Kepler's struggle to understand the motion of the untwinkling orange "star." Could I forget my modern notion of its orbit and imagine Mars riding an epicycle on a crystalline sphere encircling the Earth? Hardly. Kepler's mind penetrated the mystery of planetary orbits; my own mind could not forget the lesson.

The telescope shows Mars to be a polar-capped and gray-green mottled world spinning on its axis. Through Earth's thick and turbulent atmosphere I struggled to make out yellow clouds in the thin air of Mars and, though I knew the optics could reveal nothing smaller than a hundred miles, my mind's eye saw the world of craters, valleys, and volcanoes that space probes have shown. Could I see only the desert Mars astronomers imagined twenty-five years ago, before the first space probes? Hardly. Once learned, the lesson is hard to forget.

And what of the Mars of the imagination, the Mars of "artist's conceptions"? Speak of Mars and you'll describe a world with a red sky, red sand, and what? — ancient rivers? space-suited explorers? sandworms? To the artist there are no limits but the limits of imagination.

In this issue of *ASTRONOMY* you'll find three visions of Mars: Mars as a naked-eye planet in *Sky Almanac*; Mars as a telescopic world in our summary of the first half of the 1988 apparition; and Mars as a world of the imagination, in which *ASTRONOMY*'s art director Tom Hunt joined two dozen artists in search of a Mars on Earth — and found one in Iceland.

How will Mars look to people two hundred years from now, I wonder, when another age of exploration has passed? Will they see the Red Planet as the site of the Solar System Olympics, "live" from Olympus Mons? Will Mars be a profitable colony or an independent state? Will our Martian descendants chuckle as they read a holographic version of the December 1988 *ASTRONOMY*? Will they be able to forget the Mars they will know and imagine the Mars we see now?

Sincerely,



Richard Berry
Editor-in-Chief

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Notes on Astronomy Education

I'm all for astronomy in our schools! ("Astronomy in Our Schools" by Stephen Cole, September 1988). Eight years ago I had an enthusiastic fifth-grade teacher who turned me on to astronomy. Without this teacher I would probably not have bought my telescope or subscribed to *ASTRONOMY* to learn about the subject each month.

My high school offered chemistry and physics, which I took, but no astronomy class. The college I will attend has a planetarium but few astronomy courses.

An achievement I am proud of is exposing my nine- and twelve-year-old neighbors to the wonders of the sky. I hope they continue to explore astronomy with me, because they will not have the chance to explore it in school. — *Kelly Lutterman, Anderson, Indiana*

I teach fourth grade and am the chapter leader for our school's Young Astronaut club. I have little technical knowledge of astronomy, but I do have an incredible thirst for knowledge and an immense fascination with the vastness of space. I use my limited knowledge, combined with my enthusiasm for astronomy, to face the toughest of all questioning minds — a child's mind.

I am also a victim of our educational system's neglect in the area of astronomy education. I had little astronomy in high school and none in college, and I am unable to receive credit for astronomy classes through the local university's masters degree program.

I would love to take courses and ask the questions I have wanted to ask. I would love to fly aboard NASA's Kuiper Airborne Observatory, to attend an astronomy workshop, to have a telescope available to use with my students. . .

I want to improve my knowledge and, in turn, the knowledge of my students. Let's get astronomy back in the classroom, but first let's get it to our educators. — *Sean M. McLaughlin, Mishawaka, Indiana*

I take respectful exception to a statement by Jeanne E. Bishop in "Astronomy in Our Schools." Ms. Bishop said, "Astronomy is unique among the sciences because so many other disciplines — chemistry, physics, biology, geology — are incorporated in it."

Astronomy is not unique in its reliance on other disciplines. Other sciences, including my own field of geology, also lean heavily on many other disciplines — chemistry, physics, biology. So important is this interdependence that we have well-defined specialties like geochemis-

"Your Eyepiece Has Given Me the Most Pleasant Case of Insomnia Imaginable"

Tom Lorenzin, author of "1000+ Guide to Deep Sky Observing"

Discover Type 2 Nagler Eyepieces

These new designs extend the Nagler concept to impressive new performance levels, while retaining the basic advances of the original Naglers:

- 82° apparent field
- full field correction
- fast aperture correction, to f/4

New Features Include:

First: longer focal lengths produce wider true fields of view.

Second: full exit pupil correction permits comfortable night and day use.

Third: fold-down rubber eyeguards are included for maximum comfort and dark adaptation.

Fourth: they are relatively lightweight, moderately sized, and include knurled rubber grip rings for easier handling.

Design Goals

The basic Nagler series has already achieved image correction 10 times better than previous wide angle eyepieces (study in "Telescope Making" titled "The Nagler 13, a Remarkable Telescope Eyepiece"). We felt that extending the apparent field or image correction levels beyond that of the original Nagler series would not yield significant practical gains, but that extending the focal lengths would offer enormous potential for spectacular low power, wide-angle viewing.

In order to produce longer focal length Naglers, two practical limits had to be overcome:

- 1) Substantial physical size, weight, and cost increases would be impractical.
- 2) Scaling up exit-pupil aberrations would be unacceptable in our judgement. Although the 13mm Nagler eye-



piece provides extremely sharp images, exit-pupil aberrations require a large (nighttime) eye pupil opening to encompass the full field. For this reason, daytime viewing with the

13mm Nagler is not recommended. Eye positioning is just too sensitive with the 7 element design to consider focal lengths longer than 13mm. The 9mm and shorter Naglers don't show this sensitivity.

Nagler Type 2: The design breakthrough!

The patented (#4,747,675) 8-element design achieves pupil aberration correction far beyond any eyepieces produced with such large apparent fields. Each model is a unique design, with eye relief similar to the 9mm Nagler, yet surprisingly compact, lightweight and affordable. Extensive computer-aided design efforts and the use of new glass types retain the superb full-field and fast aperture sharpness of the 7-element Naglers. Our pioneering lens edge-blackening and multi-coating techniques also maximize contrast.

A special rubber eye-

guard aids viewing comfort, eliminating stray light and enhancing dark adaptation. This helps in detecting faint, delicate nebulosity and comets. The eyeguard is a delight on cold nights too.

20mm Nagler Type 2

Has the largest true field in the series. Yet this eyepiece, (strictly for 2 inch focusers) is comparable in size and weight to a 13mm Nagler. There's nothing like this 20mm for viewing large open clusters, galaxies and nebulae. It gives a 4.5mm exit-pupil with f/4.5 telescopes. Daytime viewing is also simply stunning!

16mm Nagler Type 2

Offers far more true field than the 13mm Nagler, yet is smaller and lighter. Great day or night performance with any telescope.

"There is nothing like this eyepiece (20mm Nagler) for viewing large deep-sky open clusters, galaxies, and nebulae. Under ideal conditions at Yosemite National Park, I was treated to incredible views of M8, M13, M17, M22, M31, and M33. I had believed that my C-8 would never perform visually with photographic quality, but my observations with the Nagler rivaled the detail in good astrophotography and even surpassed it at times. I was amazed and deeply satisfied. Thank you for the ultimate eyepiece."

Ben Cohen, CA

12mm Nagler Type 2

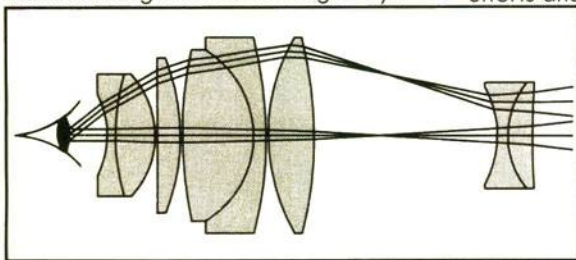
As superb as the 16mm, but with higher magnification. An excellent alternate to the 13mm Nagler, which has a longer eye relief for people who MUST wear eyeglasses to correct severe astigmatism.

The 16mm and 12mm Type 2 Naglers work beautifully with Tele Vue Barlows. These 1 1/4" barrel eyepieces can also be used with 2" focusers.

As Dr. Jack Marling says: "The eyepiece is half the telescope, so use the best... Tele Vue."

Tele Vue™

20 Dexter Plaza, Pearl River, NY 10965
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WE'RE SERIOUS ABOUT HAVING FUN WITH ASTRONOMY.

try, geophysics, and planetary geology.

Crossing disciplinary boundaries is healthy and almost unavoidable nowadays if any science is to keep abreast of the times and to contribute to society. — *Frank B. Conselman, Ransom Canyon, Texas*

"Astronomy in Our Schools" points out what most amateur and professional organizations would like to see more of: an early educational introduction to astronomy. Many organizations try to make up for the slack of the schools, but that's not enough.

Amateur astronomers everywhere must heed the student's call for a better understanding of the cosmos and do everything they can to bring the universe a little closer to home. — *Paul D. Webb, West Columbia, South Carolina*

An Unique Halloween Treat

One of the most rewarding aspects of astronomy is sharing the hobby with the uninitiated. A few years ago I found a great way to do just that.

On the last several Halloweens the weather has cooperated and I have been able to give the trick-or-treaters an extra treat. I set my telescope up on the driveway of my suburban home, pick a bright object like the Moon or Jupiter, and let the kids have a look after collecting their candy. The sense of wonder and excitement these views give children is something to behold.

If you are thinking of doing something like this, though, I have a few words of advice. Never leave the telescope unattended. Sandbag the mount. Use a sturdy stepladder with some kind of handhold for the little ones to reach the eyepiece. Help the children up and back down. Also be sure to have information on what parents should look for when they're shopping for a telescope. — *John R. Spain, Harvey, Louisiana*

Correction

In "The Chaotic Material between the Stars" by Lys Ann and Steven Shore (June 1988), Michael G. Hauser was incorrectly identified as the project scientist for IRAS.

H. H. Aumann was the project scientist, and Hauser was a member of the IRAS Joint Science Working Group.

ASTRONOMY welcomes comments, suggestions, corrections, and additional information on articles and astronomy. Send your letters to: ASTRONOMY Letters, 1027 North 7th Street, Milwaukee, WI 53233. Letters may be edited for length and clarity. □

A NATION HUNGRY FOR ASTRONOMY

by Gary Sampson

Planetarium director at Wauwatosa West High School, Wauwatosa, Wisconsin, and participant in the Project STAR curriculum program

This summer I traveled to the People's Republic of China with a group of high school exchange students to see how astronomy fits into the society and schools of this vast country. We encountered a nation hungry for astronomy and eager to learn from us.

As a teacher/leader in the first American-Chinese Youth Science Exchange, sponsored by the nonprofit People-to-People International foundation established in the 1950s to promote cultural exchanges, I toured five Chinese cities with thirty-three American astronomy students. During our stay we visited observatories and schools and talked to amateur and professional astronomers throughout the country.

Astronomy has a long history in China. The Chinese were among the first people to make accurate observations of the motions of the Moon and the planets, eclipses, sunspots, aurorae, meteors, and the supernova of 1054. They made crucial observations of Comet Halley in ancient times and are renowned for their work on calendars. It is a tradition of which the Chinese are very proud.

Modern astronomical research in China is conducted at facilities like the radio astronomy array at Miyun Station and the solar telescope tower at Huairou Station. Chinese amateur organizations, unlike their American counterparts, are closely affiliated with the professional community, because they were founded by the staffs of the regional observatories and universities. These clubs generally operate through the Chinese school system.

But the widespread dissemination of astronomy in China faces many barriers. Astronomy is given only cursory treatment in Chinese textbooks before the tenth grade, which is the last year of schooling for most Chinese students, and it is only a tiny part of the senior high level geography course. Chinese schools have little funding for observatories or planetariums; the classrooms reminded me of rural Wisconsin in the 1950s.

Although Chinese amateur astronomers have the same interests as their Western counterparts — astrophotography is very big in China — relatively few amateurs have access to telescopes through the universities and professional observa-

tories. There is basically no commercial market for telescopes because the population cannot afford them. (A small telescope costs the average Chinese worker eight months' salary.)

The Chinese made it abundantly clear that they want to cooperate, not just on the professional level but also through exchanges with amateurs. The current government permits an extraordinary openness to Americans. At no time were we thwarted as we asked questions about astronomy. There was a genuinely relaxed atmosphere between the Chinese and American students.

But history has shown us that such conditions are subject to the vagaries of politics. Who knows how long the present feeling of goodwill between our countries will last? We need to take

The Chinese want more astronomy in their schools too. Will we help them?

advantage of this opportunity now.

Much can be done. Wang Shougan, president of the Chinese Astronomical Society, has called for more astronomy exchanges between American and Chinese teachers and students. By sending astronomy textbooks, curriculum guides, and magazines, we can help Chinese teachers and students who are severely handicapped by lack of funds for such materials.

The exchange would not be a one-way street by any means. The Chinese are very eager to share the historical treasures of their astronomical heritage with the West. Several of our student guides, seeing we were interested in this heritage, offered to translate Chinese documents into English. We need to support such work so the ancient astronomical tradition as well as modern research can be shared by the rest of the world.

The Chinese place a high priority on astronomy not only as a means of fostering the scientific development of their country but as a vehicle for world peace. In their view there is no better way to help bring about international peace than for today's youth — the leaders of tomorrow — to be involved in the cooperative study of the cosmos. We should join them in this effort. □

Take yourself on "an automated self-guided tour of the universe" with the Meade® CAT.™

"... so quick you really *can* observe 100 objects an hour, as the ads say ... If you prefer to spend your time observing deep-sky sights rather than hunting for them, then the CAT is ideal." — *Sky & Telescope*, November, 1987.

"... the CAT is a true time saver, a device that can show hundreds of objects per night ... the payoff is an automated, self-guided tour of the universe." — *Astronomy*, December, 1987.

What it is: The Meade CAT ("Computer Aided Telescope") system is a revolutionary telescope accessory that leads Schmidt-Cassegrain telescopes from object to object, in *seconds*. The graphic display on the CAT's console enables the observer to locate *any object in the CAT's 8,199-object memory within, literally, 5 to 10 seconds or less.*

How it works: Included with the CAT are 2 precision optical encoders that mount on the telescope and sense the telescope's position in RA and Dec; the encoders permit the location of even the most obscure objects with 25 times the precision of standard setting circles. Using the CAT's large, red-illuminated crossline display, the observer manually moves the telescope to the position dictated by the crosslines. The CAT unerringly positions the desired object precisely in the center of the telescopic field. In addition, digital readouts on the display console continuously display R.A. and Declination.

Object Database: Included within the CAT's computer memory database are the positions of 8,199 objects — *virtually every object of interest in the entire celestial sphere, North and South:*

- ☐ **7,840 Deep-Space Objects**, including all 110 Messier objects, plus 7,730 other objects contained in the Computerized New General Catalog (CNGC) — galaxies, nebulae, star clusters, objects of every description in the sky.
- ☐ **351 Bright Stars**, used primarily as CAT reference objects, including 100 interesting double and multiple stars.
- ☐ **8 Major Planets:** The positions of all 8 major planets are included in the CAT's

memory, a feature not available on any other computerized telescope system. In seconds you can locate Mercury, even in bright twilight; observe Uranus and Neptune; or photograph the day-to-day motion of 14th-magnitude Pluto. The CAT enables the positioning of these and the other major planets in the center of the field, *easily and rapidly.*

The Meade CAT attaches in minutes to Meade and other brands of Schmidt-Cassegrain telescopes and may be adapted by the user to other types of telescopes as well.

Models and Pricing

CAT #9000:	for all Meade 2080 models	\$1495
CAT #9008:	for Meade 2080/LX6	1495
CAT #9001:	for all Meade 2120 models ..	1495
CAT #9010:	for Meade 2120/LX6	1495
CAT #9003:	for C8 fork-mounted models ..	1495
CAT #9005:	for C11	1495

The CAT, shown on a Meade Model 2080/LX5.

NEW!

Digital Setting Circles for your Schmidt-Cassegrain!



Meade Digital Setting Circles utilize the high-technology of the CAT, but without the CAT's massive object database and other features, at a significantly lower price. Compare these specifications:

4 Operating Modes: Depress the "Mode" button sequentially and obtain:

- Mode 1:** reads out the Local Time and Sidereal Time on the 2 readout registers.
- Mode 2:** reads telescope Right Ascension and Declination. R.A. reads out to a precision of 1-min., Dec to 0.1°.
- Mode 3:** enables a digital timer for timing astrophoto exposures.
- Mode 4:** turns both registers "Off."

Optical Encoders: Meade Digital Setting Circles utilize Hewlett-Packard optical encoders for the highest level of precision and sensitivity. The encoders attach in minutes to the polar and Dec. axes. The readout unit mounts onto the telescope's rear cell, where it is *continuously visible from the eyepiece observing position as you move from object to object.*

Models and Pricing

DSC #9060:	for all Meade 2080 models	\$495
DSC #9061:	for all Meade 2120 models	495
DSC #9063:	for C8 fork-mounted models	495
DSC #9065:	for C11	495

Warranty: Every Meade CAT and DSC unit is covered by a 3-year warranty on parts and labor.

For further information: Send for your free copy of Meade Bulletin CAT/DSC, or send \$3.00 for the complete Meade General Catalog #88C. The 75-page CAT Instruction Manual is available at \$5.00.

Better still, call or visit your authorized Meade dealer; he'll be glad to answer any questions on the Meade CAT and DSC's—two of the most exciting and revolutionary telescope accessories ever developed.



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ICE VOLCANOES ON URANIAN SATELLITES

Ice is unusual stuff. If you hit it with a hammer, it shatters, and if you squeeze it in your hand, it melts. There seems to be no "give" in it short of total breakdown. And yet as any glacier shows, ice will flow if you give it time.

Two planetary astronomers at Cornell University, Daniel Jankowski and Steven Squyres, recently reported in *Science* (September 9, 1988) that a cold, creeping kind of volcanism, in which solid ice has been pushed out or extruded from a planet's interior, has modified the surfaces of at least two of Uranus' icy satellites — the first such activity ever seen in the solar system.

Jankowski and Squyres analyzed Voyager photos of Ariel, measuring the brightness of two canyons, Kewpie Chasma and Brownie Chasma, and deriving topographic profiles for them. Bordered by linear faults, Brownie and Kewpie are long, deep grooves called grabens that mark where the surface has been pulled apart. The land inside a graben lies lower than the surroundings outside, and ordinary graben floors are almost always flat or consist of broken flat segments.

Brownie and Kewpie, however, do not have flat floors — in fact, a ridge runs down the center of each, half a mile to a mile high. Because liquid water flowing into the bottom of the graben would produce a flat surface, Squyres and Jankowski conclude that the material filling the graben was squeezed into place as a solid or semisolid — the first such "ice volcanism" ever seen.

A similar kind of activity occurs on Miranda (see photo). This moon has areas of dark, grooved terrain, called coronae, which show at their edges the convex shapes typical of flow fronts.

Jankowski and Squyres examined what could force ice to extrude like putty, given the low temperatures at Uranus. Ariel would have warmed up when it accreted, but its present surface is much younger than that, and Miranda, also with a younger surface, would have heated up less during its accretion. On the other hand, both moons may have been warmed by tidal interactions with their sibling moons. Yet Squyres and Jankowski think it unlikely that the ice volcanism they have found is the result of any substantial or global heating of the moons, because this would have quickly "relaxed" the other landforms on the moons' icy surfaces.

The most probable answer appears to



DARK AND GROOVED ICE once flowed out of Miranda's interior in a newly discovered form of volcanic activity in the solar system.

be that the extruded ice had a much lower viscosity than pure water ice has. Admixtures of methane and ammonia would substantially lower the temperature at which the material could begin to flow. Jankowski and Squyres also suggest that similar activity may be found among the moons of Neptune and at Pluto.

SUPERNOVA IS MOST DISTANT STAR EVER SEEN

The most distant star ever recorded — an exploding star, or supernova — has been discovered in an inconspicuous galaxy in the distant galaxy cluster known as AC118. The supernova, which was near the detection limit of the telescope used, lies approximately 4 billion to 5 billion light-years from Earth.

Danish astronomer Hans Ulrik Norgaard-Nielsen made the discovery on August 9, 1988, with the Danish 1.5-meter telescope at the European Southern Observatory (ESO) in La Silla, Chile. He is a member of a group of astronomers who have been searching for supernovae in distant galaxies for the past few years.

The astronomers sample many distant galaxy clusters, taking an image of each and comparing it with an earlier image of the same cluster. A supernova shows up

as an additional spot of light — often as bright as an entire galaxy — if one of the images is taken shortly after the supernova's light reaches Earth. By "subtracting" one image from the other, only the extra spot of light remains and the supernova is revealed.

This supernova shone at 22nd magnitude at discovery, some 4 million times fainter than the faintest objects visible to the naked eye. Early spectra indicate that the supernova is a Type I supernova, the brighter of the two main types.

Once the spectra are analyzed, astronomers will be able to tell if this supernova — which occurred several billion years ago — is similar to the more recent Type I supernovae located closer to Earth. If so, this would give astronomers an important tool for measuring distances in the universe.

If all Type I supernovae have the same intrinsic brightness, researchers could use them as an independent method for verifying large extragalactic distances. Right now the only reliable way astronomers have for measuring such great distances is based on the expansion of the universe.

THE DAY THE EARTH CAUGHT FIRE

Two recent studies paint conflicting but equally apocalyptic pictures of what happened at the end of the Cretaceous period and the start of the Tertiary, 65 million years ago, when a great many species of plants and animals, including the dinosaurs, became extinct.

Three years ago several chemists identified soot in clay deposits laid down at the boundary between the Cretaceous and Tertiary. The same team has now re-examined this soot layer using samples from five sites in Europe and New Zealand and extended the analysis. Their result was published in *Nature* (August 25, 1988).

The scientists — Wendy Wolbach, Ian Gilmour, and Edward Anders of the University of Chicago, Charles Orth of Los Alamos National Laboratory, and Robert Brooks of Massey University in New Zealand — found that the soot layer coincides exactly with an abrupt enhancement of iridium. This element, rare on Earth but relatively abundant in the solar system, is widely thought to be the "smoking gun" for a large meteorite or asteroid impact.

Looking at the samples in detail, the

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scientists found that all the clay deposits — whether in Europe or New Zealand — had the same amount of soot and contained traces of retene, a hydrocarbon residue that can result when coniferous trees are burnt. They also found that the soot from all the sites had the exact same combination of carbon isotopes. This makes it all but certain that a single gigantic forest fire, touched off by the impact, soon spread to engulf the entire Earth.

"It is likely that trees were knocked down, dried, and ignited by the impact," the scientists said. They also point out that the blast from the asteroid strike would have leveled forests for five hundred miles in every direction, providing plenty of splintered fuel to create and feed a firestorm. Once alight, a firestorm burns unchecked until it runs out of fuel.

The second study, involving rock outcrops near the Brazos River in Texas, presents strong evidence for an immense tidal wave at the Cretaceous-Tertiary boundary and implies that the asteroid hit the ocean.

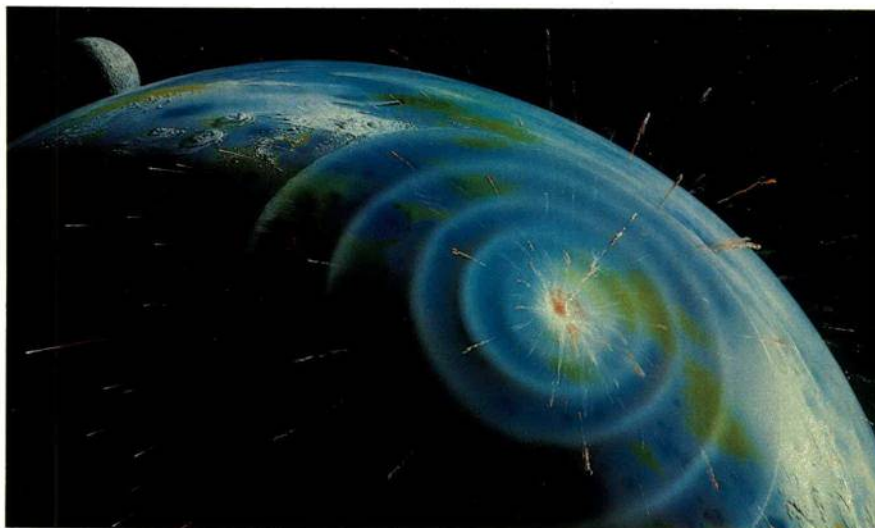
Joanne Bourgeois and Patricia Wiberg of the University of Washington, Thor Hansen of Western Washington University, and Erle Kauffman of the University of Colorado, Boulder, describe in *Science* (July 29, 1988) how a deposit of deep-water mudstone is interrupted at the Cretaceous-Tertiary boundary by a two-foot-thick sandstone layer.

The sandstone is coarse in texture and contains shell fragments, fish teeth, wood debris, and jagged pieces of mudstone up to four inches across. It is coarsest at the bottom and gradually becomes finer until, at the top of the layer, it gives way to mudstone again. The upper mudstone is identical to the lower — except that it contains different species of microfossils and has plenty of iridium.

The authors propose that an asteroid struck the open ocean, sending out a tidal wave initially two or three miles high but that subsided to only about three hundred feet by the time it raced over the site where the outcrops now lie.

There it would have stirred up the water all the way to the bottom, washing in sand, debris, and mudstone fragments. When the wave passed, the coarsest and heaviest materials settled first, producing a deposit that grew steadily more fine grained toward the top. The last act in the drama would be the slow burial of the sandstone by organic material and clay, laced with meteoritic iridium from the atmosphere, as the deep-water mudstone deposition continued.

At this stage the two reports, both apparently well established, stand largely



A TIDAL WAVE initially two or three miles high engulfed what is now Texas 65 million years ago when an asteroid hit the ocean.

in opposition to each other. It is hard to see how to reconcile fire with water — how, in short, a global forest fire could result from a five-mile-diameter rock hitting the ocean. More work may uncover two separate but temporally close impacts, but for the time being the puzzle remains unsolved.

PLACID OORT CLOUD MODEL BASHED AGAIN

Recent calculations by University of Colorado astronomer Alan Stern show that comets orbiting the Sun in the Oort cloud are likely to undergo so many collisions among themselves that their surfaces will be cratered and fractured to a depth of several feet. His report appeared in *Icarus* (March 1988).

This finding is in conflict with the generally accepted model for the Oort cloud, in which the cloud is a region of undisturbed material orbiting far from the Sun and largely unchanged since the earliest period of solar system history.

Impacts by small bodies — both other comets and debris from previous collisions — will "garden" the surface of any comet to a depth of several feet. "The impacting stuff has sizes that mainly range from golf balls down to sand," notes Stern. "About once a year some comet hits another." But because the impacts occur at relatively low speeds, "only one comet in a hundred or a thousand has actually been destroyed."

Because any comet that swings through the inner solar system is unlikely to present a clean, untouched appearance, astronomers looking for primordial solar system material in comets are out of luck — unless they can get samples from well below the fragmented surface layers.

PLANETARY NEBULAE YIELD DISTANCES TO GALAXIES

A technique that uses planetary nebulae as extragalactic distance indicators promises to help astronomers establish the distances to nearby galaxies more precisely and to greater distances than conventional methods. The technique capitalizes on the similarity of the absolute magnitudes of the brightest planetary nebulas in different galaxies.

Astronomers are always looking for better ways of measuring the distances to galaxies. Unlike distance estimates to the nearest stars, which are accurate to within 2 or 3 percent, the estimates to the nearest galaxies are, at best, accurate to about 10 percent.

The inexactness arises because the bright distance indicators — massive stars, Cepheid variables, star clusters, and supernovae — are few in number, often located in the dusty regions of spiral galaxies, and display a wide range of color and magnitude properties. Moreover, because the nature of these objects is not well understood, their true luminosities are often in question.

However, George H. Jacoby and Robin Ciardullo of the National Optical Astronomy Observatories, and Holland C. Ford of the University of Michigan believe planetary nebulae neatly circumvent these problems and consequently make a more accurate distance indicator. The team has so far identified nearly two thousand planetary nebulae in nearby galaxies, including M31, M32, and M81.

One reason extragalactic planetary nebulae make excellent distance indicators, Jacoby said, is that "there is an upper limit to how bright a planetary can be." In all of the galaxies included in their survey, the brightest extragalactic

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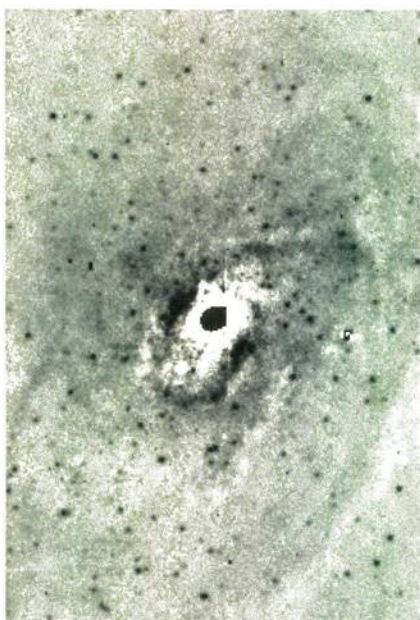
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EACH BLACK SPECK is a planetary nebula belonging to the spiral galaxy M81. The galaxy's image has been suppressed and the stars subtracted.

planetaries have absolute magnitudes of about -4.4 .

The presence of such an upper-magnitude cutoff implies that the brightest planetaries have similar luminosities in all galaxies. This commonality can thus be used to advantage in determining distances: if you know how intrinsically bright a source is, you can better estimate how far away it is.

Planetary nebulae have several advantages over distance indicators such as Cepheid variables and massive stars, said Jacoby. For one, planetary nebulae are found in all types of galaxies, including ellipticals, which are poor in other dependable distance indicators. Planetaries can also be used to determine distances twice as great as Cepheid variables — which have a limit of about 23 million light-years. And unlike Cepheids, which reside mainly in the dusty arms of spirals, planetaries are located throughout galaxies, most significantly in dust-free regions above the disk. Thus, planetaries can be found that are not reddened by dust (a factor that can bias the luminosity and, hence, the distance estimates).

Jacoby said he, Ciardullo, and Ford plan to push the technique to greater distances this spring by trying to determine the distance to the Virgo cluster of galaxies. Heated debate over the distance to the Virgo Cluster persists because there is no other accurate method for deriving distances to galaxies this far away.

Space News

GREAT OBSERVATORY #3 BEGINS

After initially being dropped from the NASA budget earlier this year and enduring the skepticism of Congressional critics this spring, the *Advanced X-ray Astrophysics Facility* (AXAF) — the third of NASA's four "Great Observatories" — has been funded as a new start mission this year.

If the project proceeds according to schedule, AXAF will be launched from the space shuttle in 1996. It will join the *Hubble Space Telescope* and the *Gamma Ray Observatory*, both of which are scheduled for launch in early 1990. When the fourth Great Observatory, the *Space Infrared Telescope Facility*, is launched in the late 1990s, astronomers will be able to make observations across the electromagnetic spectrum with instruments of unprecedented accuracy.

AXAF faced particular scrutiny in Congress because of the *Space Telescope*, which ran into cost overruns and technical problems during its development. "When we look at the experience of the *Space Telescope*, which originally was going to cost \$490 million and then was raised to \$1.2 billion, it is pretty difficult for us to have any confidence in the industrial community and in NASA to begin the development of a new major telescope," said Edward Boland (D-Mass.), chairman of the House subcommittee that oversees NASA appropriations.

The \$1.5 billion project eventually received \$17 million for the current year, down \$10 million from NASA's original request. To placate Congressional concern over possible cost overruns, NASA is building AXAF one step at a time. Instead of working on the observatory's mirrors and spacecraft simultaneously, NASA will build the mirrors first and start on the spacecraft only after the mirrors have been successfully tested.

NASA recently chose TRW Inc., prime contractor on the *Gamma Ray Observatory*, to build AXAF and awarded the company a \$500 million contract to begin work on the mirrors. The x-ray mirrors on AXAF will have five times the resolving power of NASA's previous x-ray satellite, the *Einstein Observatory*, which was active from 1978 to 1981.

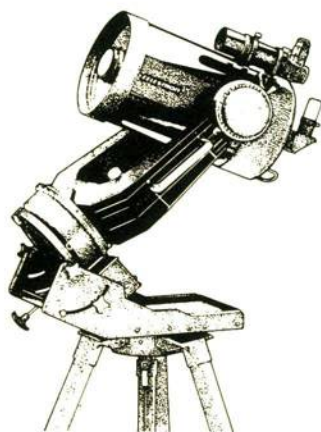
X-ray mirrors are very different from optical telescope mirrors because x-rays can only be focused when they skim the surface of a mirror. Instead of the usual dish-shaped mirror, AXAF's mirror is a set of six cylindrical mirrors nested inside one another.

Since 1981 NASA has been working on x-ray mirror technology that would produce the accuracy needed for AXAF. Although a prototype mirror will be ready for testing next month, the final go-ahead on AXAF will have to await the successful testing of one of the real mirrors, scheduled for completion in 1991.



THE CYLINDRICAL MIRRORS (center) of NASA's \$1.5 billion *Advanced X-Ray Astrophysics Facility* will begin catching x-rays in 1996.

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MARTIAN BALLOONING IN LITHUANIA

American and Soviet scientists spent a week in August ballooning in Lithuania in preparation for the 1994 Soviet Mars mission. The Soviet Union plans to explore the Martian surface with experiments carried aboard balloons, and the Lithuanian test flights showed the Soviets how various payload concepts would work (see "The Soviets Advance into the Solar System" by Donald F. Robertson, July 1988).

The test flights were sponsored by the Planetary Society of Pasadena, California, in cooperation with Titan Systems of Los Angeles and the Soviet Institute for Space Research. American experience in ballooning is valuable to the Soviets because there are no ballooning organizations in the Soviet Union.

The main purpose of the balloon flights was to test how different science payloads react with the surface. An antenna was carried aboard the balloon to see how stable it would be on take-off, during flight, and on landing.

"The stability test was positive," said Louis Friedman, executive director of the Planetary Society. "We were surprised at how stable the antenna was. It hung over the balloon and didn't swing." On the Martian mission an antenna would be used for electromagnetic sounding to measure soil conductivity and thus infer if there is water in the Martian soil.

The team also tested the landing of two types of payloads: the balloon gondola and a "snake." The snake is a flexible cord containing instruments inside. "With the snake there were no shock waves in the balloon and we had a smooth landing," Friedman said. "But we found that if you're going to land something solid like the gondola, the shock waves will rip the balloon apart."

Seventeen people flew over fifteen flights in a 108,000-cubic foot balloon sent to the Soviet republic of Lithuania by the Planetary Society. The Lithuanian balloon team will communicate the results of the tests to the French national space agency, which is developing the balloons for the Soviet Martian mission.

Three additional balloon tests are being planned in Siberia, possibly Iceland, and the Mojave Desert in California, where earlier tests have been conducted by an ad hoc group from the Planetary Society, Titan Systems, Caltech, Utah State University, and the Jet Propulsion Laboratory. The Planetary Society is involved in a study of the Mars balloon to develop the concept and to organize American involvement in the project.



GETTING READY to test instruments from a balloon are Tom Hensheimer of Titan Systems (left), Victor Kerzhanovich of the Soviet Institute for Space Research (middle), and Ed Johnson (right), a U.S. balloon pilot.

NOCTILUCENT CLOUDS MAY ENDANGER SHUTTLE

NASA is studying the threat posed to the space shuttle by noctilucent clouds — mysterious clouds located high in Earth's atmosphere. NASA's chief concerns are that the poorly understood clouds could cause the loss of flight control during re-entry and could damage the thermal tiles that protect the shuttle from the heat of re-entry.

The threat is most severe for shuttle missions flying in high-inclination orbits. The clouds, which are unrelated to normal weather clouds, normally appear only at latitudes above 50° and only in the summer. However, no one is sure that the clouds do not occur at lower latitudes or in the winter. (See "Clouds of the Twilight" by David McConnell, July 1987.)

Scientists are still not sure what noctilucent clouds are, although they believe the clouds are composed of water vapor frozen onto the surface of tiny dust grains. These icy particles might be able to erode the thermal protection coating on the shuttle's tiles. Because the clouds occur at an altitude where the spacecraft experiences intense heat during re-entry, any damage to the tiles at this stage could be catastrophic.

A simulator study has demonstrated that large navigational errors could also occur if the shuttle were to pass through a noctilucent cloud as it re-enters the atmosphere. The study showed that those errors could be corrected after passage through the cloud, but the cloud also caused considerable rolling motion and changed the angle of the shuttle's entry.

Although most shuttle missions fly in equatorial orbits, some space science and Department of Defense missions require the high-inclination orbits where noctilucent clouds could be a factor. NASA's review of the potential hazards could force changes in the re-entry paths used by shuttle missions in such orbits.

Amateur News

MARS STARS AT ASTROFEST

Over three hundred amateur astronomers traveled to Camp Shaw-Waw-Nas-See near Kankakee, Illinois, for the annual Astrofest convention in September. Sponsored by the Chicago Astronomical Society, the event featured talks by amateurs, displays of the latest home-built telescopes, chats between newly made friends, and this year's bonus — Mars.

Shortly after they arrived on Friday evening, September 9, participants began setting up dozens of telescopes for the night of observing to come. Unfortunately dust in Earth's atmosphere and what appeared to be a significant amount of smoke from the Yellowstone forest fires diminished the sky's transparency. Deep-

sky observing was significantly impaired, but the planets were virtually unaffected because the seeing held steady. And Mars was the star of the show.

Many observers had their finest-ever views of the Red Planet. Solis Lacus, the "Eye of Mars," was especially dark and prominent. The Martian South Polar Cap was easily visible in small telescopes. Observers wandered from telescope to telescope looking for the best view they could get and studying the dark markings on the planet's surface. Several dozen people observed until nearly dawn on Saturday morning.

Those who got sleep could listen to a variety of talks by amateur astronomers on Saturday morning. Dan Troiani, an

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assistant Mars Recorder for the Association of Lunar and Planetary Observers, presented an update on the opposition. Joe Ulowetz discussed this year's Perseid meteor shower. Dan Joyce and Dan McConaughy described how they built their 10-inch Tri-Schiefspiegler, a multi-mirror telescope that provided some of the previous night's finest views of Mars. Steven Lordcotton explained why amateurs might want to hold a Messier Marathon.

Saturday night brought the invited lecture, given this year by Arizona comet hunter David H. Levy. Levy described what drives backyard astronomers to search for new comets and how to go about looking for them. "The best advice is to search the western evening sky and eastern morning sky every day you can," said Levy. "I never would have dreamed I could find a comet; after finding four, I know they're out there waiting to be seen."

After Levy's talk attendees wandered out under a darkening sky. The final night of observing offered steady seeing but poor transparency, so many of those on the field again looked at Mars and Jupiter.

Fortunately many excellent telescopes were available for Mars watching, including the 10-inch Tri-Schiefspiegler, a 7-inch refractor brought by Roland Christen of Astro-Physics, a 6-inch $f/27$ Herschelian reflector, and several other large refractors. Those who had big Dobsonians stopped-down their apertures with off-axis masks and enjoyed gazing at dark markings on the surface of Mars.

PRIVATE OBSERVATORY FOR PUBLIC EDUCATION

Two amateur astronomers are constructing one of the first private observatories in the United States to operate an education program on a regular basis. Observatory curator Richard Ryan of Clear Lake, Wisconsin, and Jon Chase, president of Northern Sky Telescopes in Minneapolis, hope to have the observatory open by next spring. The observatory, located on Ryan's farm, houses a 25-inch Newtonian reflector.

Chase and Ryan plan to make the observatory available to junior high and high school groups from Minneapolis and west-central Wisconsin. "We want teachers to select small groups of a dozen or two highly motivated students for a high-quality astronomical field trip," said Chase. His hope is that the observatory will help science teachers enrich the school curriculum, even if the curriculum does not include astronomy. "We're



LONG ROWS OF TELESCOPES awaited darkness last September at the Astrofest convention near Kankakee, Illinois.

going to offer the teachers a fully prepared program that's exciting and oriented to the kids," said Chase.

"We're two guys who had a dream and have realized it," said Ryan. "We're building a telescope and we're making it for other people to learn from and enjoy too." The observatory will be open for a public star party at least once a year.

"When people look through a big telescope, it can just knock the socks right off their feet," said Ryan. "Astronomy and space science [are] at the forefront of public interest, but when people look at the actual sky, that's when the wonder turns into adventure."

"Building the telescope privately has made it happen very quickly," said Ryan. "We started in March and we're shooting for Christmas to have it operating." The 25-inch $f/5$ Newtonian will be mounted on a German equatorial made by Opticraft. The mirror is being made by Galaxy Optics.

"We're going for secondary education — junior high and high school kids," said Ryan, "because that's when kids start to realize where they are, that's when the universe falls into place for them."

"We want this to be something we'll continue to enjoy too," said Chase. "We're not a club, we're not a university. We want to keep it small, and we don't want to do 'here's the dome, here's the telescopes, here's the exit' type tours. We want individuals to have time to view."

Interested area science teachers may call Chase at (612) 545-6786 to discuss programs for next summer.

NEW MEXICO INN CATERS TO ASTRONOMY BUFFS

This past summer the first resort catering exclusively to amateur astronomers opened in Sapello, New Mexico. Located about sixty-five miles northeast of Santa Fe, the Star Hill Inn opened in June and acquired a 24-inch telescope several months later. It offers the use of a large telescope under a dark sky and a relaxed atmosphere in the Sangre de Cristo Mountains (altitude 7,200 feet) for amateurs to "get away from it all under the stars."

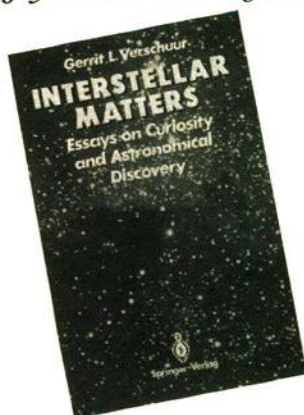
The Star Hill Inn is operated by amateur astronomers Phil and Blair Mahon, who have long dreamed of visiting such an astronomical resort. Rather than waiting for something that might not occur, they built their own astronomical inn.

The inn is doing brisk business, with visitors from fifteen states and Canada. Staying at the inn isn't like visiting a typical hotel: it's more like attending a private star party. The inn accommodates a maximum of ten people at a time, but the Mahons are "beginning construction of our third unit so that we can host up to fifteen people."

Guests can either bring their own telescopes or rent an 8-inch SCT or 13.1-inch Dobsonian. In November the inn added a 24-inch computer-controlled reflector, available for \$10 per night.

Although the Star Hill Inn is the first such facility in the United States, more of these retreats may be built as dark skies become more and more of a luxury. □

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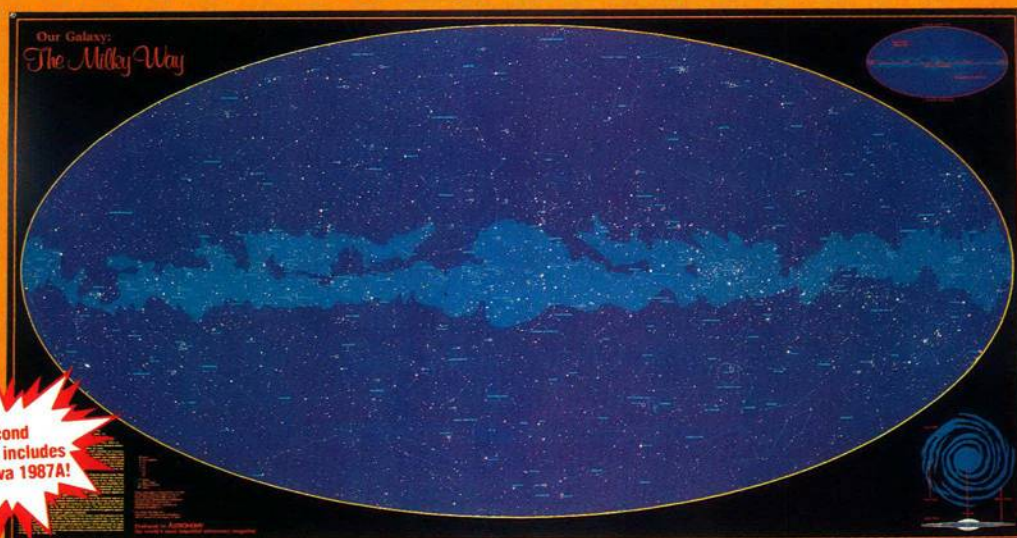
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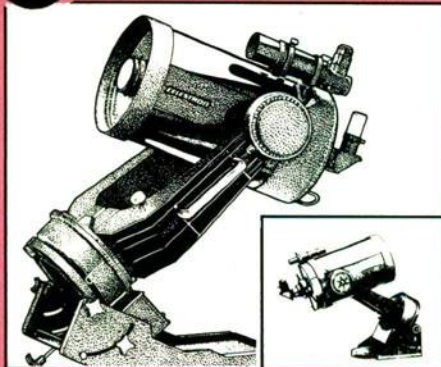
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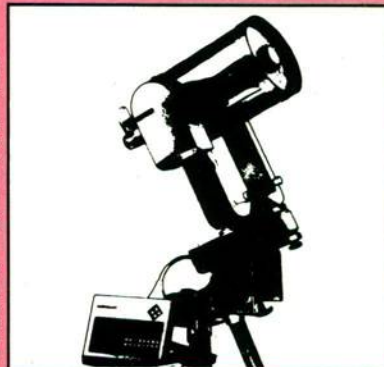


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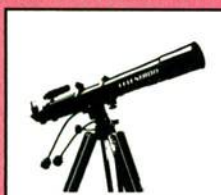


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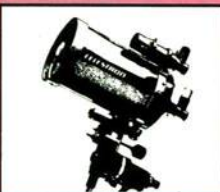
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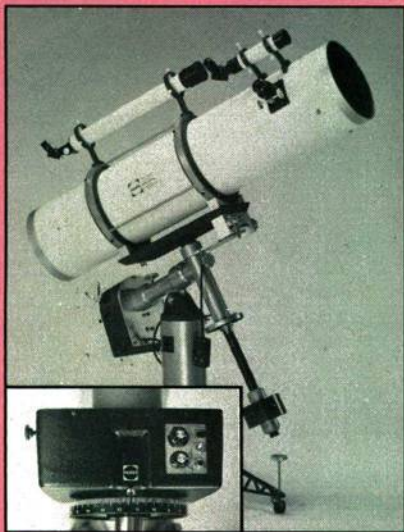
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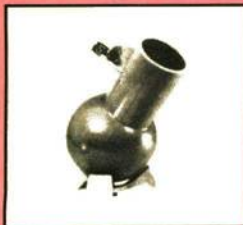


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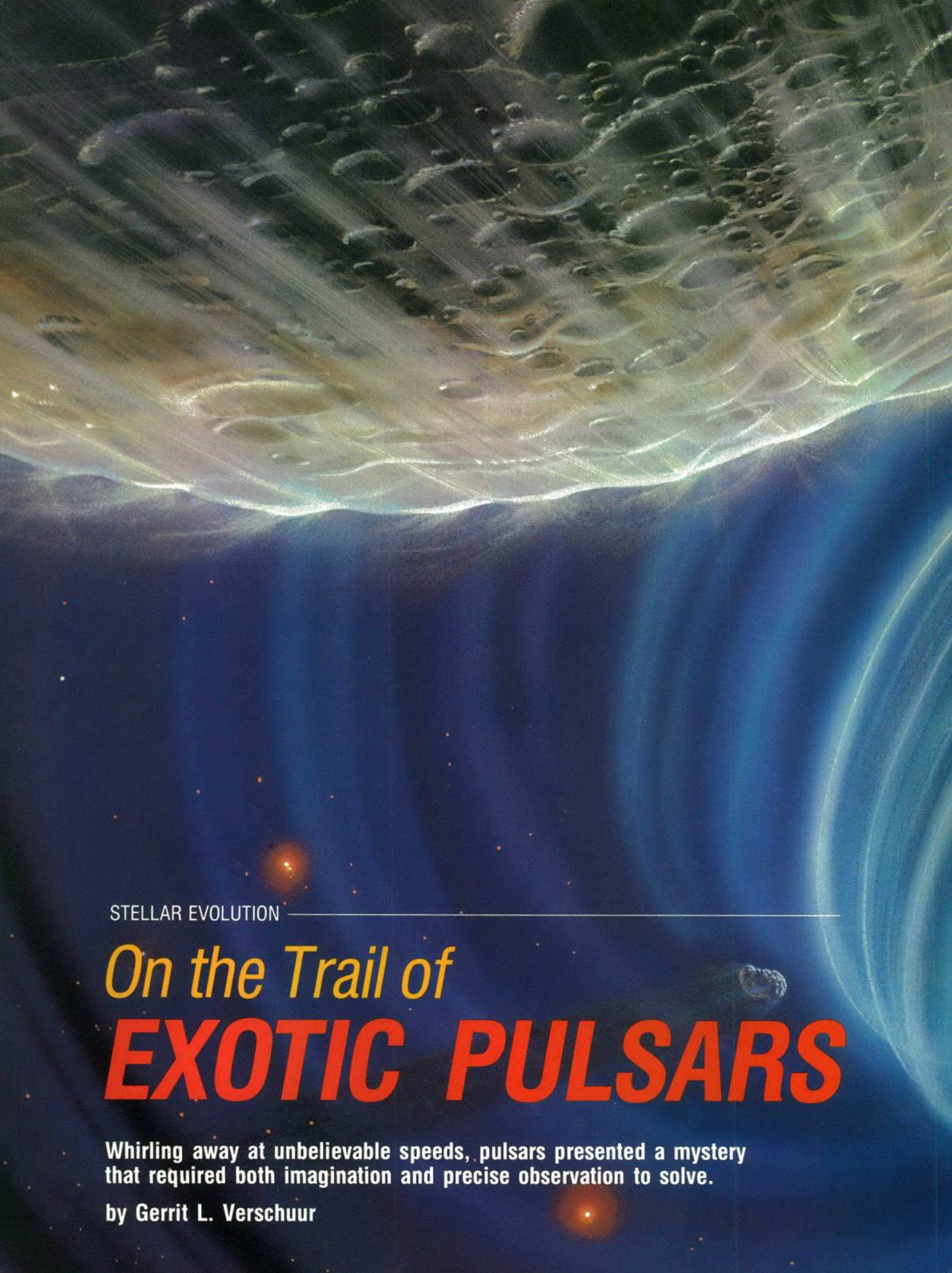
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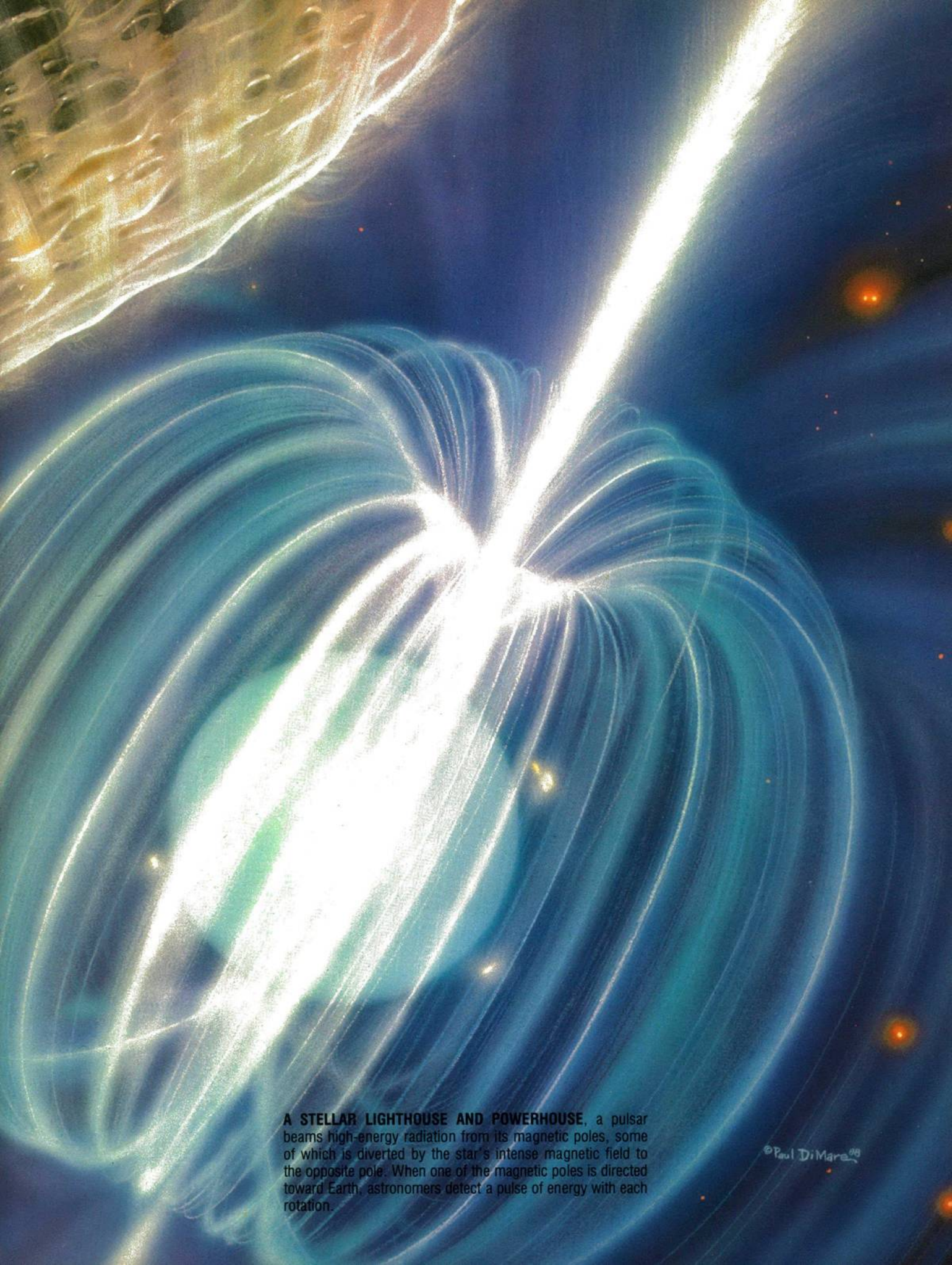


STELLAR EVOLUTION

On the Trail of
EXOTIC PULSARS

Whirling away at unbelievable speeds, pulsars presented a mystery that required both imagination and precise observation to solve.

by Gerrit L. Verschuur



A STELLAR LIGHTHOUSE AND POWERHOUSE, a pulsar beams high-energy radiation from its magnetic poles, some of which is diverted by the star's intense magnetic field to the opposite pole. When one of the magnetic poles is directed toward Earth, astronomers detect a pulse of energy with each rotation.

© Paul DiMare '88

The story of pulsars is a story of one discovery leading to another, sometimes in apparently random ways yet in the end widening our horizons on the nature of these unusual objects. The main characters are inquisitive researchers who push back the barriers to knowledge and publish, often in little-read reports, what they find. Later, other researchers treat such snippets as pieces of a jigsaw puzzle and assemble them to form a larger picture. And yet, like Alice in Wonderland, the explorers in our adventure weave a still-unfolding tale that grows "curiouser and curiouser."

The scene opens on a June day in 1987 in the library of the National Radio Astronomy Observatory (NRAO). Outside the windows fallow fields stretch between parallel ridges of West Virginia hills. The radio astronomer standing by the window is not looking at the scenery. Donald Backer, a visiting observer from the University of California at Berkeley and discoverer of the first millisecond pulsar, is taking a break. In his case that means thumbing through the shelves filled with "pre-prints." He was seeking, he said later, gems on the sea-shore.

A preprint is the prepublication version of a scientific report that will appear in a technical journal. These documents are piled deep and wide on the NRAO library shelves; it would take weeks to read them all. However, Backer was using the approved method of panning for metaphorical gold: you scan the title, occasionally read an abstract and then, perhaps, you read the contents.

He slowly waded through report after report until he came across one by Richard Strom of the Westerbork Observatory in the Netherlands. Backer's heart leapt. Other readers might have thought that this report was just another collection of data. But to him this was like finding the Holy Grail.

Backer read that Strom had discovered a pointlike radio source in an object known as CTB 80. This apparently minor fact galvanized Backer into action. He went to the nearest phone and called his colleagues in California. "We brought in the SWAT team," he said.

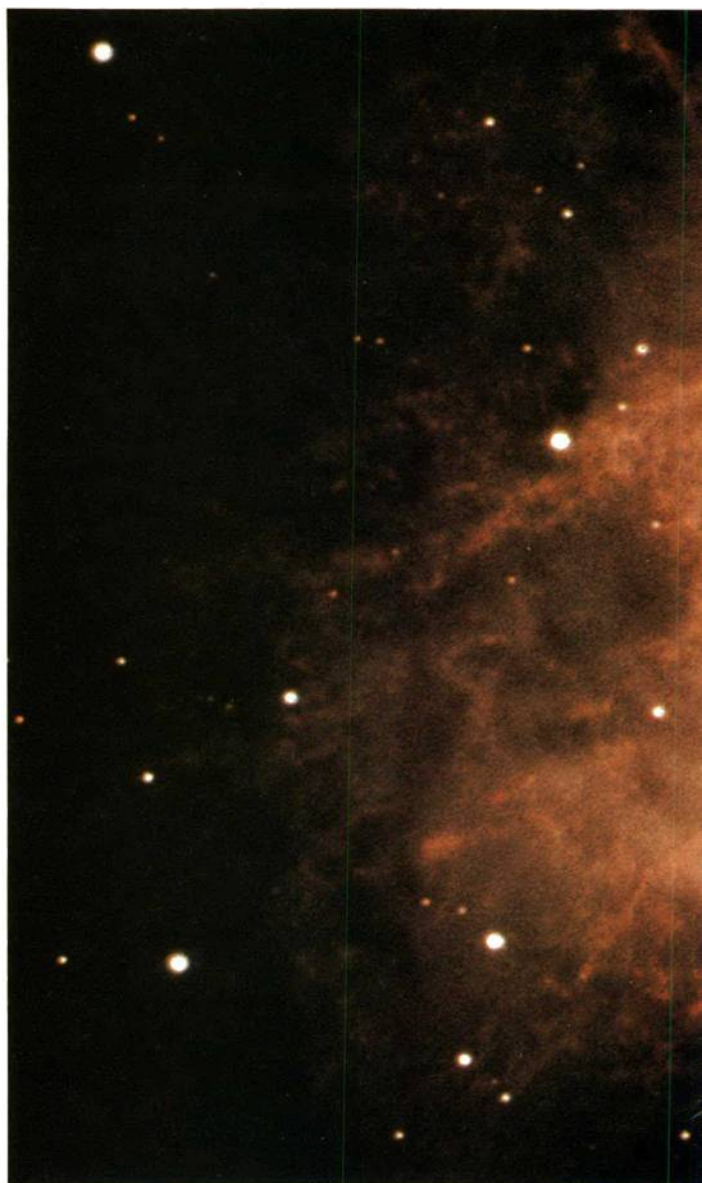
As point man in a new search for millisecond pulsars — enigmatic beacons in space that caught most astronomers by surprise when discovered in 1982 — Backer was doing the major part of a new survey using the 300-foot radio telescope himself. But Strom's report said this pointlike source in CTB 80 was weak, and that meant the programs and observing techniques had to be significantly changed. So Backer called for help.

A Stellar Cataclysm

But the story really begins with a discovery made over nine hundred years earlier on July 4, 1054. Some archaeoastronomers believe a group of American Indians awakening that morning in Chaco Canyon, New Mexico, saw a new star glowing brightly near the crescent Moon. The magnificent spectacle filled them with awe. The Indians painted the memory of this apparition on a rock face, the first publication — a prehistoric preprint as it were — reporting a natural phenomenon.

On that same day, far to the east, Chinese astronomers also saw this new light in the sky. A "guest star" they called it. They were to watch it for the next two years until it finally faded from view.

Centuries later, telescope-wielding astronomers began to survey the heavens and unknowingly came across the remains of the 1054 event. Some astronomers



had noticed fuzzy patches of light among the stars, which they called "nebulae." One such astronomer was Charles Messier, an inveterate comet hunter, who was frustrated by how much nebulae and star clusters looked like comets. He was particularly frustrated by one of these objects just northwest of the southern horn in the constellation Taurus. In fact, this object and others that appeared blurred or fuzzy in his poor-quality telescope prompted Messier to make a catalog listing the positions of these bogus comets.

"What caused me to undertake the catalog," wrote Messier, "was the nebula I discovered above the southern horn of Taurus on September 12, 1758, while observing the comet of that year. This nebula had such a resemblance to a comet, in its form and brightness, that I endeavored to find others so that astronomers would not confuse these same nebulae with comets just beginning to shine."

The first entry in his catalog, M1, was something far more abstruse than a comet "just beginning to shine," however. Messier had found the aftermath of an exploded star, the event witnessed in China and perhaps in the western United States in 1054. Nearly a century later William Parsons, the third earl of Rosse, observed the cloudy object with his newly constructed 72-inch



telescope and noted that M1 looked not unlike the carapace and claws of a crab. Because of Parsons' description, M1 was to become known as the Crab Nebula.

But what *is* the Crab Nebula? The clues appeared first in 1921 when John Duncan compared his photographs with others made twelve years earlier and discovered that the gas filaments were moving outward. The photographs also revealed two small stars nearly at the center, nestled deep in the wispy skirts of the nebula.

It was one of these stars that in 1942 Walter Baade suspected of being the burned-out core of the explosion of 1054. Rudolph Minkowski agreed. This star was the dead center of the nebula, they said, and perhaps it provided the energy to keep the nebula shining after the explosion. The core of the star still seemed to be shining normally. Well, not really "normally," said Minkowski, when he concluded the star's temperature was 500,000 kelvins. That was far hotter than any stellar surface temperature was expected to be. But he was wrong on another score as well. It wasn't a star.

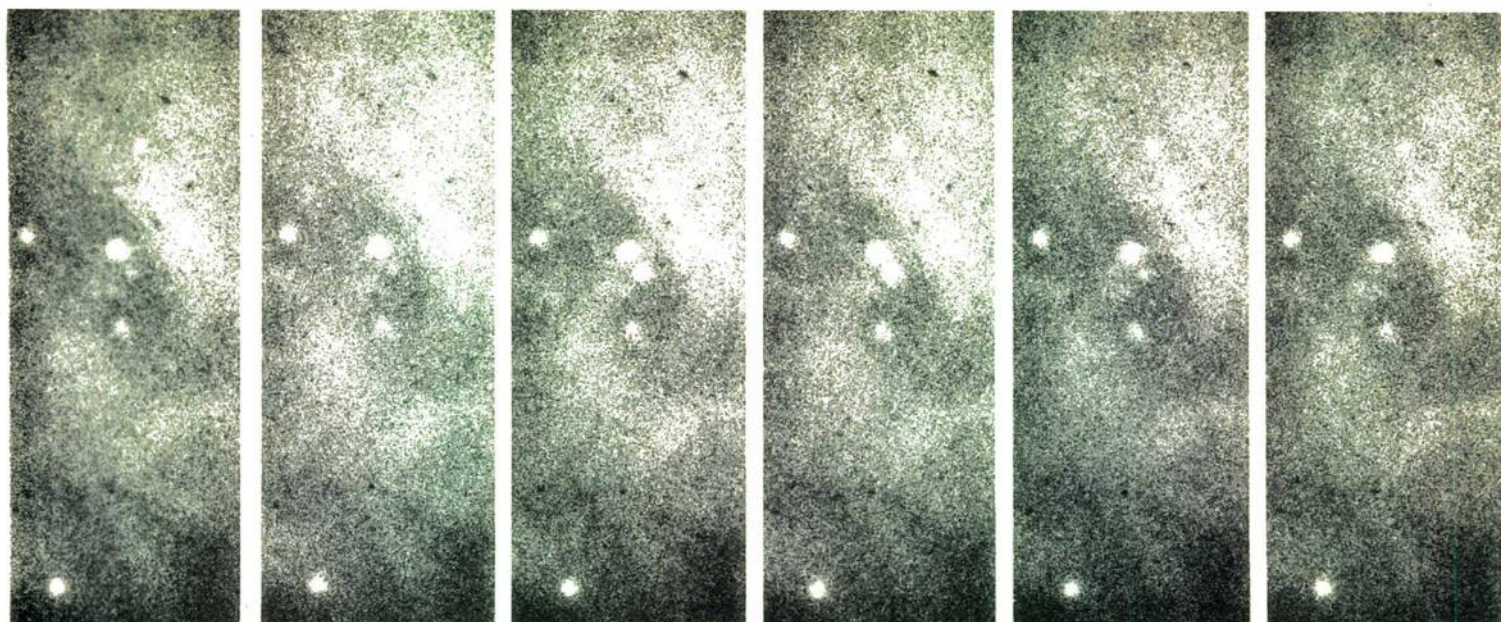
In the 1930s Karl Jansky and Grote Reber had discovered radio waves from the Galaxy. While the evolution of radio astronomy, required to pursue their discoveries, was put on hold during World War II, the technology needed to study radio waves from space was

AT THE CENTER OF THE CRAB NEBULA lies the pulsar created in a supernova explosion. This event may have been depicted by Indians in Chaco Canyon, New Mexico (inset).

being developed as a spin-off from radar research. After the war this new technology really got under way.

In 1949 John Bolton of the Commonwealth Scientific and Industrial Research Organization in Culgoora, Australia, began a survey of radio "noise" from the southern sky. He used an antenna and receiver operating at 100 megahertz (MHz). Operating at Dover Heights near Sydney, Bolton found six directions in the heavens where radio emissions seemed to peak. One was in the constellation Taurus. With Gordon Stanley he then set out to narrow the location of what he called the Taurus A radio source. They set an antenna on a cliff top on the North Auckland Peninsula in New Zealand so they could watch the newly discovered radio source rise over the sea.

To radio waves at 100 MHz the sea looks like a mirror. As a result, when the source rose into the sky, its radio waves entered the antenna both directly and after reflecting off the water. From the source's point of view there were two antennas, one on top of the cliff



CAUGHT IN THE ACT, the Crab pulsar is revealed in this series of photos of the central part of the Crab Nebula. The photos each span a 1/30-second interval.

and one below it — the reflected image. Bolton and Stanley had constructed a “virtual” interferometer consisting of two antennas separated by a distance twice the height of the cliff. Yet they used only one antenna! With it they were able to observe the radio sky more clearly and extract more information from individual sources. With any radio interferometer the resolution of the system depends on the separation between the individual antennas, and the greater the separation, the greater the resolution.

With this piece of technological wizardry they observed one of the minor discrete sources of galactic radio frequency noise, Taurus A, and were able to narrow its location to the position of the Crab Nebula. Within a year or so Iosif S. Shklovsky of the Soviet Union suggested that the Crab’s radio emission was produced by energetic electrons traveling at nearly the speed of light and spiraling around magnetic fields in the nebula. But this still did not explain why the object would be shining nine hundred years after the explosion.

The First Pulsar

In the late 1950s radio astronomers at the University of Cambridge under Martin Ryle began a 159-MHz study of the radio sky. It came to be known as the third Cambridge — or 3C — survey. At the same time Robert Wilson and John Bolton at Caltech performed a 960-MHz survey of the Milky Way. The object that was to draw Don Backer’s attention in the Green Bank library two decades later was entry number 80 from that old survey — CTB 80.

Back at Cambridge they were cataloging source after source, about 471 of them. Then the astronomers improved the system and started again, producing the 4C survey at 178 MHz.

One of the researchers, Margaret Clark, noticed that some of the radio sources “scintillated,” that is, they seemed to change slightly in brightness from moment to moment. This happened only when the source was close to the Sun and had a small diameter on the sky.

Radio scintillation is similar to the twinkling of star-

light: variations in the brightness of stars as their light passes through irregularities in Earth’s atmosphere. Radio waves passing through clouds of electrons boiling away from the Sun in the solar wind suffer a similar effect.

By the mid-1960s quasars had been discovered, and the Cambridge researchers realized that a quick way to find new quasars was to search for radio sources that scintillated, because quasars were starlike. Led by Anthony Hewish, the Cambridge group decided it would build a new radio telescope exclusively to search for interplanetary scintillation.

They elicited the support of hard-working summer vacation students to build a bargain-basement device. The antenna system operated at 81.5 MHz and consisted of a field of wires strung between poles.

The original scintillation survey, meanwhile, had turned up an anomaly. A pointlike radio source was found in the Crab Nebula. Obviously this bright source was not a quasar because its redshift was not as great as known quasars. Its existence was a mystery, yet the source served as a convenient reference object for other low-frequency radio observations.

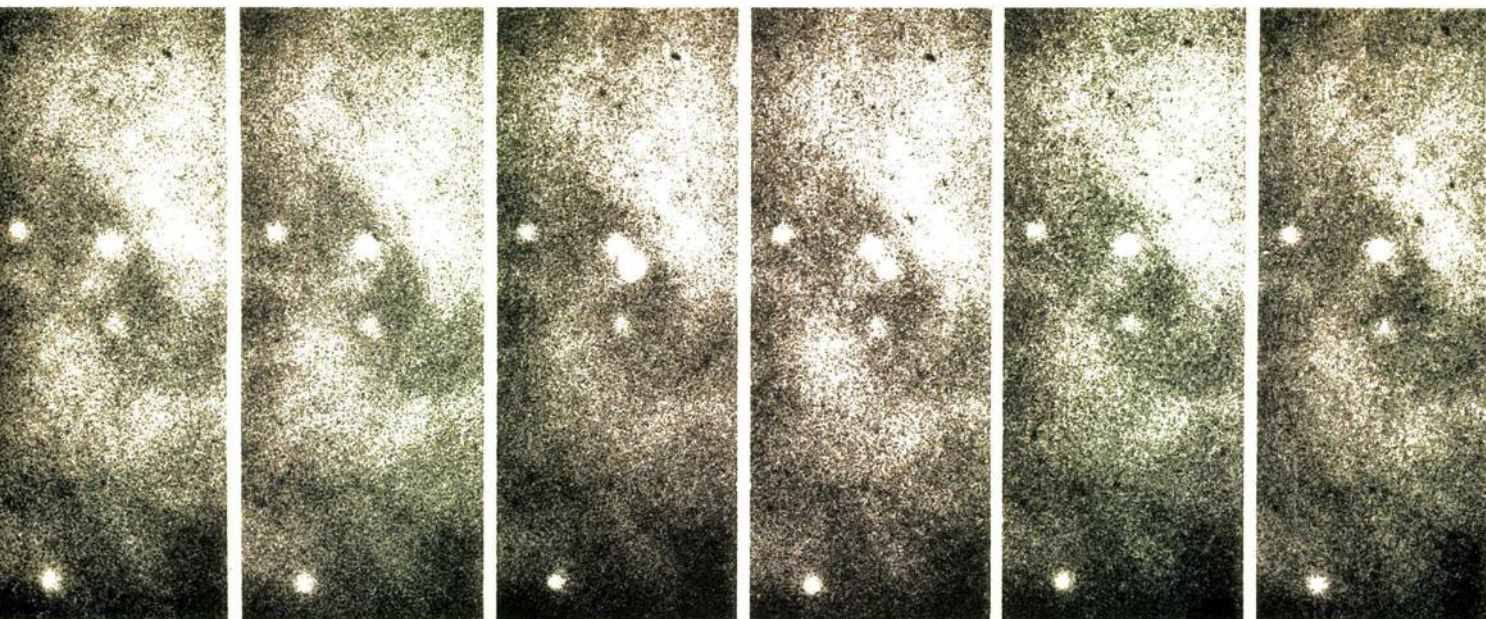
In July 1967 the Cambridge telescope came into operation and almost immediately its receivers began churning out miles of paper chart using four strip recorders. Jocelyn Bell, at the time a graduate research student, looked at all the data and saw what they were looking for: scintillating radio sources during the night.

But that was impossible! Only small-diameter radio sources near the Sun scintillated. The Sun wasn’t up, so scintillation should not be observed. It had to be terrestrial interference pretending to be scintillations, Bell was told. Many days later she noticed that several of the “little bits of scruff,” as she described them, appeared to cross through the antenna beam at slightly different times each night. The daily shift was four minutes, the difference between the solar and stellar days. This meant the objects were amongst the stars.

The nighttime scintillators, it turned out, were not scintillators at all but mysterious sources of radio pulses arriving with remarkable regularity. A new word was coined to describe them — pulsars.

A Lighthouse in Space

The discovery of pulsars burst upon the astronomical world in early 1968. Within a year the theoretically



mindful, rallying to the challenge of explaining the strange new objects, had come up with a plausible explanation. These were neutron stars, they said, objects consisting entirely of neutrons packed to enormous density in a tiny volume of space. The star's core collapses just before the upper layers explode outward as a supernova. The magnetic poles on such a star emit a beam of radiation that sweeps through space like a lighthouse.

Thus, 1968 was declared open season in the search for pulsars. Because the Crab Nebula was connected with a supernova, and supernovae spawned pulsars, the Crab became a prime target for David Staelin and Edward Reifstein, both visiting the NRAO. For a while Dave shared an office with me and a colleague. We wondered at the time why he isolated himself behind closed doors with Ted. We suspected — correctly it turned out — that they were poring over their exciting data and didn't want any "leaks."

They soon proclaimed that a pulsar had been found in the Crab Nebula, and soon thereafter its period of 30 times per second was measured by the radio telescope at Arecibo, Puerto Rico. This was far more rapid than the leisurely once-every-second-or-so characteristic of the original pulsars. Thus, the notion took hold that young pulsars spin rapidly, but as they age, they slow down. The idea that the neutron star was a final phase in stellar evolution also received its first blessing.

The radio astronomers kept observing and found the Crab pulse rate to be slowing down, like a child's spinning top. Enter now Jeffrey Scargle of Lick Observatory. In 1969 Scargle published photographs he had taken of the Crab Nebula, which showed that small wisps around the central star were changing in brightness and position. Could this star be the pulsar?

The radio pulsar, meanwhile, stuttered. It would speed up briefly and then resume its normal slow-down. Scargle watched the Crab closely and found that about sixty to eighty days after a pulse "glitch" the wisps around the stars changed a little. Something emitted by the neutron star, bursts of energy no doubt, had to be causing the filaments to glow.

The next challenge was searching for optical pulsations. William Cocke, Mike Disney, and D. J. Taylor, using the telescope atop Kitt Peak near Tucson, Arizona, succeeded in catching the Crab pulsar in the act on Jan-

uary 16, 1969. They blinked the shutter on their video camera coincidentally with the pulsar. First they timed the shutter to catch the pulsar when it was on and then when it was off. Lo and behold, there it was.

The very star that Baade and Minkowski had suspected as the core of the stellar explosion really was blinking on and off. But it was not a star in the normal sense of the word. It was a neutron lighthouse beaming light, radio, and x-ray energy into space. The pulsar's energy beam, thought to emanate from the pulsar's magnetic poles, sweeps past Earth and when viewed in a normal manner — as in a photographic exposure of many minutes — seems to shine steadily. A radio telescope operating in a standard observe mode detected this object as a compact radio source.

Curiouser still, it didn't take long before astronomers recognized that the gradually slowing pulsar was losing as much rotational energy as the nebula emitted in the form of light and radio waves. This fact explains why the nebula is still radiant centuries after the explosion. Deep inside the expanding gas cloud a neutron star spins at a dizzying rate. As the pulsar spins, its magnetic field interacts with the magnetic field and gas in the nebula to feed rotational energy into the nebula. This mechanism is the source of the highly energetic flow of electrons that Iosif Shklovsky suggested caused the nebula to shine. It is this transfer of rotational energy into the nebula that causes the pulsar to slow down.

The Twinkling Pulsar

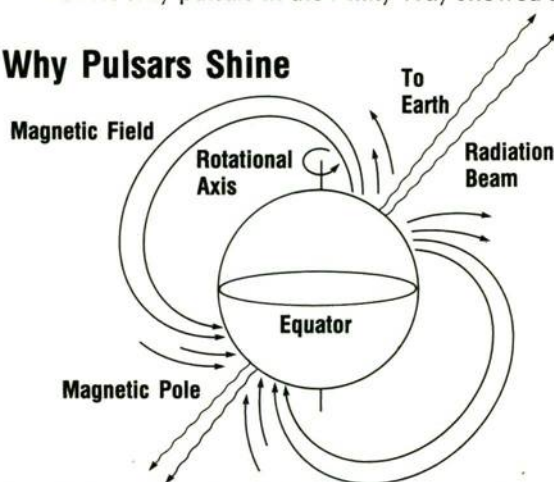
Now the story takes a decidedly odd turn. By 1979 astronomers had settled back to delight in their explanations of pulsars. But something odd was bugging Backer and others, including Bill Erickson at the University of Maryland's now defunct low-frequency radio telescope at Clark Lake in California. Their concern was about to add a wild card to the pulsar deck. One of the 4C survey radio sources was confusing the understanding of interplanetary scintillations. Known as 4C 21.53, this was one of the scintillators that had been discovered back in the 1960s. The problem was that it was located where it shouldn't be: in the Milky Way. That in itself was hardly significant, except that sources in the Milky Way should not scintillate!

As mentioned earlier, small-diameter radio sources show interplanetary scintillation when their radio waves

pass through electron clouds close to the Sun. These sources are mainly quasars. However, a quasar that happens to shine through the Milky Way will no longer appear as a small-diameter radio source because of another pervasive effect called interstellar scattering. The radio waves from a pointlike radio source that pass through clouds of ionized material between the stars would be bent this way and that, so that when the waves reach the radio telescope, they appear to come from a small extended region on the sky. Although very small, this scattering effect spreads out the radio image slightly. A quasar seen through clouds in the Milky Way therefore appears larger than it really is, preventing interplanetary scintillation, because that phenomenon requires a point source. (In other words, in the presence of interstellar scattering you don't expect interplanetary scintillation.)

At first only pulsars in the Milky Way showed scin-

Why Pulsars Shine



A pulsar's energy arises from electrons accelerating along magnetic field lines issuing from the magnetic poles. As the neutron star spins, the radiation sweeps across space.

tillation, but other radio sources and radio galaxies did not. A sort of "zone of avoidance" existed in which these better known and easily identifiable radio sources shone steadily. However, this orderly state of affairs didn't last. A number of sources refused to conform. One of these, 4C 21.53 in the constellation Vulpecula, scintillated merrily despite its location in the Milky Way.

To get to the bottom of this scintillating matter, astronomers Jim Rickard and Will Cronyn used the Clark Lake radio telescope and discovered that at 34 MHz this source not only scintillated wildly but was extremely bright. The lower the radio frequency, the brighter the source. It had what is known as a steep spectrum, far steeper than any expected for a normal radio-emitting object such as a supernova remnant or a distant radio galaxy.

No simple physical model could immediately explain this phenomenon, so for a while some astronomers dubbed it as a member of a new class of objects — "scintars" — yet another bizarre beast in the skies. Others expected it to be a pulsar, which also has a steep spectrum. However, beginning in 1979, searches for the expected pulsar signature failed to turn up anything. This is what caused Backer to be so concerned.

The 4C 21.53 story became more confusing because a rare error in the original survey introduced a positional

inaccuracy in the 4C catalog. This was not known until Bill Erickson, using the VLA, found that two sources displaced in right ascension had masqueraded as one 4C source. Then Miller Goss from Groningen in the Netherlands used the Westerbork Synthesis telescope and discovered that the westernmost of these sources consisted of two objects. One was an extended nebula on the side of which a pointlike radio source was located. Once the direction of the point source was known, the pulsar search began again. And it failed again!

Backer insisted it had to be a pulsar and explained why it wasn't being seen. To him the similarity between this source and the compact object in the Crab Nebula was striking. He reasoned that interstellar scattering might be smearing the pulses so they couldn't be seen even with the sophisticated search strategies he was using at the time. So he wrote a paper suggesting that the pulsar was flashing very fast, so fast as to border on the absurd: perhaps a hundred times per second.

"Too speculative," the referee of his paper objected. His prediction would not be published. His only hope lay in trying harder in another search, this time looking for pulses arriving much faster than anyone had formally predicted or the unknown referee could believe in.

Then in November 1982 at the Arecibo radio telescope the great moment arrived. Shrinivas Kulkarni, a member of a team of astronomers from Berkeley, found evidence for pulses in September, but attempts to confirm the signal failed. Now a huge amount of new data was recorded and analyzed and revealed the signal that had been suspected back in September.

Don Backer described watching the pulse signature rising out of the noise. "This was one of the real high points in my career," he said calmly. "I will treasure this moment for the rest of my life. The fact that it existed, that these pulses were there, was really stunning."

The next day a more refined display was set up that allowed the pulses from the object to be seen on the video terminal. It was cataloged PSR 1937+214. The years of persistence had finally paid off.

Pulsar PSR 1937+21 flashed once every 1.6 milliseconds. This was the first *millisecond* pulsar. The period translates to a frequency of 642 MHz, which is E flat above high C on the piano keyboard. Its eerie sound could be heard when Mike Davis of Arecibo Observatory made a recording of the signal.

Thus in 1982 Don Backer, Shrinivas Kulkarni, Carl Heiles (also from Berkeley), Mike Davis, and Miller Goss published their discovery paper that began in a style expected from sober scientists. "The radio properties of 4C 21.53 have been an enigma for years," they wrote without a hint of elation. "Whoopee!" would have been a fairer introduction.

Sustaining the Spin

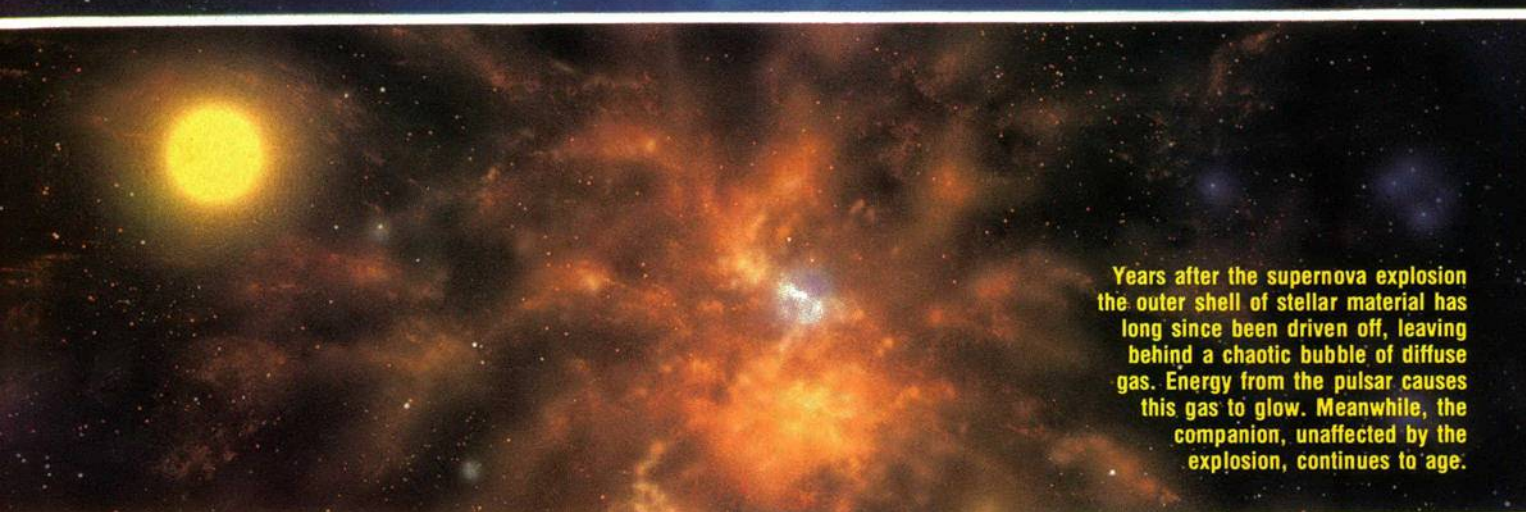
But what had they found? The pulsar was hardly slowing at all. That meant it was very old. It was flashing frantically — 642 times per second — which suggested it was very young. It also had a nebula around it, so it was probably old. In brief, the millisecond pulsar didn't fit anyone's models.

One explanation for its incredible period appeared very tempting. Something was speeding up the pulsar. But how was that possible? In answer, basic physics allowed only one scenario. A lot of matter dumped onto the neutron star would cause a spin-up. Just as ice skater Brian Boitano speeds up his rate of spin on ice by pull-

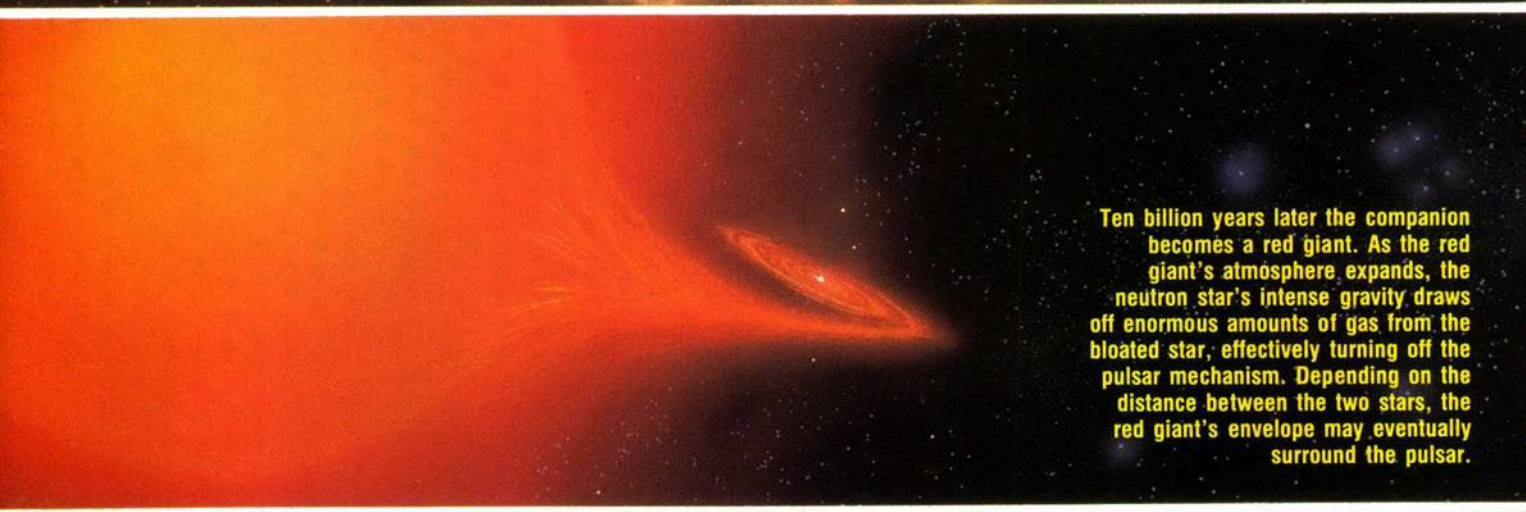
The Birth of a Millisecond Pulsar



Pulsars don't start out with the phenomenally short periods of millisecond pulsars; they must be "spun up" by the intervention of a companion star. In this example a binary star system containing a massive star and a Sunlike companion evolve together over a period of about 10 million years. The massive star eventually becomes a supernova; the core collapses into a spinning neutron star.



Years after the supernova explosion the outer shell of stellar material has long since been driven off, leaving behind a chaotic bubble of diffuse gas. Energy from the pulsar causes this gas to glow. Meanwhile, the companion, unaffected by the explosion, continues to age.



Ten billion years later the companion becomes a red giant. As the red giant's atmosphere expands, the neutron star's intense gravity draws off enormous amounts of gas from the bloated star, effectively turning off the pulsar mechanism. Depending on the distance between the two stars, the red giant's envelope may eventually surround the pulsar.

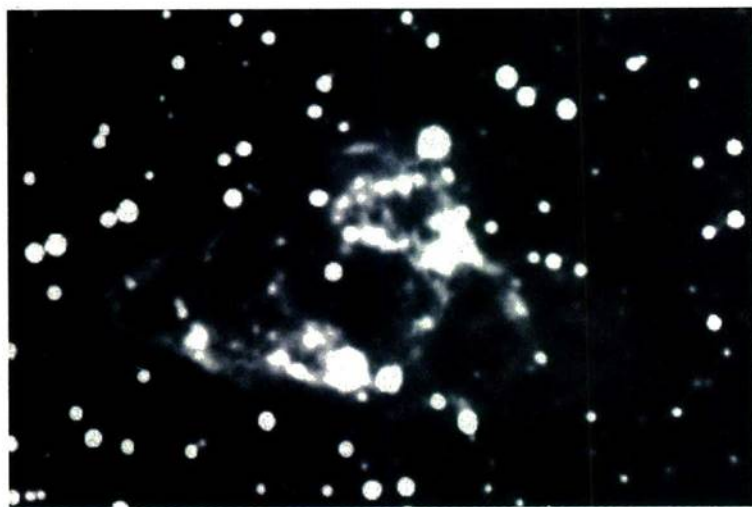


Material from the red giant falling on the neutron star speeds up the neutron star's rotation, in some cases to hundreds of times its original speed. When the red giant's envelope dissipates, the pulsar shines forth again, this time as a millisecond pulsar. Meanwhile, the red giant's white dwarf core either gradually dissolves under the powerful pulsar beam or cools slowly until it becomes a black dwarf.

ing in his arms, the neutron star spins faster if matter is dropped onto its surface. But where would the matter come from? From another star, a very nearby one.

The first binary pulsar (PSR 1913+16) was discovered in 1974 by Joe Taylor and Russell Hulse at Princeton University. This bizarre object consisted of a pulsar locked in a million-mile-diameter dance about its companion. (The pulsar, Taylor speculates, was a dead, recycled pulsar.) In the binary pulsar lay the possible explanation for the millisecond pulsar.

The scenario is as follows. A massive star locked in a close orbit around another star evolves through the supernova stage and becomes a neutron star. If observers can view the pulses of energy emitted from the magnetic fields of the neutron star, the object is termed a pulsar. Though the neutron star is only about 12 miles



A 40-MILLISECOND PULSAR causes the filaments in the supernova remnant CTB 80 to shine. This object is older than the Crab Nebula.

in diameter, it has the mass of the Sun. When the companion evolves to the red-giant stage, the neutron star begins to draw off material from the outer envelope of the bloated star. But now the neutron star finds itself in the expanding atmosphere of the giant and becomes endowed with an abundance of gas that plummets onto its surface to blend into neutrons.

A free exchange of stellar material pouring from the red giant onto the neutron star causes the dense object to begin a frantic new life, that of a reborn millisecond pulsar. The millisecond beacons from this pulsar come to us with such regularity that in one year's measurement the pulsar's accuracy is rivaled only by the best atomic clocks on Earth.

In due course the red giant may explode to form another neutron star or collapse to become a white dwarf with or without the millisecond pulsar still in orbit around it. Some astronomers also predict that if the companion continues to orbit the pulsar, it will eventually "evaporate" under the unrelenting stream of high-energy particles emanating from the pulsar.

There are still many problems with these explanations, both in the mechanics associated with the transfer of matter from one star to another, as well as whether the companion star can continue to cling to its partner

after a supernova explosion. Astronomers trying to resolve these issues have developed what they call the parthogenesis theory: the virgin birth of the millisecond pulsar that does not require that it was ever a normal pulsar. More data and a great deal of hard thinking will no doubt clarify these explanations in years to come.

Open Season on Pulsars

The discovery of the first millisecond pulsar in 1982 caused a new hunting season to be informally declared. Where better to seek one's prey than in globular clusters, where binaries may be spawned by the thousands?

The first step in the new quest was to look for compact radio sources in globular clusters, because unless one has some radio signals to work with, there was no point in searching for pulsars. In 1983 T. T. Hamilton, David Helfand, and Robert Becker used the Very Large Array radio telescope and looked for pointlike radio sources in globulars. They found one in M28.

Very quickly Bill Erickson and his collaborators found that the compact source in M28 also had a steep spectrum — in other words, it was very bright at low frequencies. This kind of spectrum is one of the distinctive hallmarks of a millisecond pulsar candidate.

With a spectrum in hand, locating the pulsar should be easy. But still no one could find a pulsar in M28!

One day Backer and his team decided that enough was enough. He, Shrinivas Kulkarni, and Trevor Clifton, visiting from Jodrell Bank, were sitting in Backer's office discussing the problem. The radio source had to be a pulsar, so why was it so elusive? According to Backer, they realized it was their job "to go out and determine what its period — merely its period — is."

The problem was that at the higher frequencies at which pulsar observers operated, the signal from the compact radio source was still very weak. The globular cluster is 19,000 light-years away, more distant than other pulsars, and finding weak pulses without knowing the period or the dispersion of the pulses is very difficult. (Dispersion occurs when radio waves, traveling at light speeds, are very slightly slowed down as they pass through the interstellar medium. The degree of retardation depends on the frequency. The broad bandwidth needed to collect sufficient radio energy from the pulses covers a wide range of frequencies, and in that band the pulses arrive at slightly different times. This dispersion of frequencies has to be compensated for in the receiving system; otherwise the pulses are blurred in time and lost.) To overcome the problem, the Berkeley group built a de-dispersing computer that corrected for dispersion as it searched for potential pulsar signatures.

"We wanted to throw the book at it," Backer said. "So we developed Plan A and Plan B." Plan A was to take the machine to the VLA, but this was not immediately convenient or practical. Backer, who was feeling a sense of urgency because of the competition with other pulsar hunters, went directly to plan B.

Plan B involved a phone call. Andrew Lyne was the radio astronomer who picked up the phone at Jodrell Bank, nine thousand miles away. Lyne, whose safaris into pulsar territory had bagged him many pulsars, had the use of the 250-foot Lovell telescope, and he was more than willing to join the project. He quickly obtained the observations and sent his data to the United States. There Backer and Kulkarni solicited the help of John Middleditch of Los Alamos National Laboratory, who had the expertise to search for periodic signals in

gigantic data sets using a Cray supercomputer. They all realized that the key to finding a faint pulsar lay in this important and very difficult step of processing vast quantities of data.

Finally in May 1987 the signals from M28 were processed. It took five hours of Cray time before a millisecond pulsar, PSR 1821-24 with a period of 3 milliseconds, was discovered in the mass of data.

The search for millisecond pulsars was now in full swing and that is why, six months later, Don Backer was at the preprint shelf in Green Bank. When Richard Strom's paper on the compact radio source in CTB 80 caught his eye, he did more than take note. Strom had been drawn to CTB 80 because it was found to exhibit x-ray emission. This source had long been suspected of being a supernova remnant and its x-ray emission seemed to confirm this. In addition, Backer realized the point source lay amongst filaments of radio-emitting gas, neatly mimicking the Crab Nebula. He was certain there had to be a pulsar in there somewhere.

The Discovery of an Old Pulsar

Backer and his colleagues had already searched this object for pulses and had found none. This had been chalked up as another negative search, and no one really worried about it until Strom's paper. To Backer, the bad news was that this compact source was far fainter than the nebula around it, too weak, in fact, to be detected by their instruments. The good news was that they could modify their system to deal with it. That is why Backer called in the "SWAT team."

Soon Kulkarni and Clifton arrived and joined in the task of making the changes. They wouldn't know if the effort was worth it until several weeks later, when they were back home analyzing their data.

Ironically, the day before the Berkeley group was about to pull the signal out of the computer, Strom's paper arrived by slow mail in Princeton. Joe Taylor, one of the old guard pulsar-hunting fraternity, read it and realized, just as Don Backer had weeks earlier in Green Bank, the significance of the compact source. Taylor immediately called his colleague, Andrew Fruchter, who happened to be at Arecibo searching for millisecond pulsars in the same general area of the sky. Fruchter took 20 minutes of data on CTB 80 and the data tape was expressed to Princeton. That night, the same night the Berkeley group members processed theirs, the Arecibo data were run through the Princeton computer. (The two systems were now capable of performing more complex data analysis.)

Both groups found their millisecond pulsar that night. PSR 1951+32 had a period close to 40 milliseconds. Eventually, the two groups agreed to publish their results in a single paper.

But why had Backer and friends missed this discovery before? They had originally obtained five good data sets but found no pulses.

"This was the only sad note in this story," Mike Davis said. When blocks of data are placed on computer tape, they are marked by end-of-file flags. At the very end of the data set a double end-of-file mark is placed that protects any of it from being destroyed by error or intruders. The mark acts like a bank vault door. You can only get past it if you are willing to tunnel through the walls. However, one of the data sets had somehow found its way into the void beyond the double end-of-file mark and was unobtainable.

Mary Stevens, a graduate student from Berkeley, had analyzed the four available data sets and had found no pulsar. After the discovery of the CTB 80 pulsar the Arecibo data were reanalyzed in Berkeley with more sophisticated programs. Still no pulsar, even though by now the astronomers knew it existed. Chance, it turned out, had blanked out the pulsar signals because of interstellar scattering! Now Stevens decided to break through the barrier on the tape, managed to pick the lock, and then processed the previously lost data set. There the pulsar was, large as life! It could have been found in 1984!

Backer summed up the moral of the story this way: "Science is cruel — you have to turn over every rock!"

Today over 450 pulsars with periods between 0.033 and 4.5 seconds are known, a stunning harvest since Jocelyn Bell first noted "little bits of scruff" on charts she conscientiously studied day after day. In addition, five millisecond pulsars have been found, three in binary systems and two in globular clusters. (The second in M4, PSR 1620-26, has an 11-millisecond pulse period.)

And CTB 80? Well, it never really looked very much like a supernova remnant at all. Faint filaments were seen but lacked the "oomph" of the Crab filaments. The new explanation is that the faint nebulosity is fired up by radiation from the pulsar: a pulsar-wind nebula. And so one thing leads to another, because the Crab Nebula may not be a supernova remnant at all but another pulsar-wind nebula.

For a long time it was a mystery why the Crab Nebula didn't look like a nice elegant shell-like object such as the Cassiopeia supernova remnant. The Crab is filled with filaments. The original explosion drives out a shell of matter with enormous violence. This plows outward and piles up surrounding interstellar matter, which causes the shell to glow with energy from the original explosion. But back in the relatively hollow bubble left behind, the energy from the pulsar wind now causes the diffuse matter left behind in the bubble to shine. In the Crab's case it shines very brightly and fills the bubble. But for CTB 80, already very old, the shell has long since gone and only some of the pulsar-wind nebula remains.

The latest report from Arecibo is that a pulsar has been found in M15. It pulses once every 110 milliseconds. Isn't that more like a normal pulsar? Or is it so old that it has slowed down and is no longer strictly a millisecond pulsar?

"This calls the millisecond pulsar label into question," Backer said, resigned to the turmoil engendered by constant discoveries that overturn cherished beliefs, even if they are but a few years old.

All this is a very far cry from squiggles on rock walls in Chaco Canyon. But the acts of our ancestors in painting on rocks or making notations on parchment were more or less signs of things to come. Today our markings may be more sophisticated, but underneath they still tell of human curiosity and our sense of wonder as we explore the universe around us. □

*Gerrit L. Verschuur is a freelance science writer and researcher who lives in Greenbelt, Maryland. He is the author of *Interstellar Matters*, which was published this month by Springer-Verlag. Verschuur's most recent article, "Will Solar Max Be Saved?" appeared in the October 1988 issue.*

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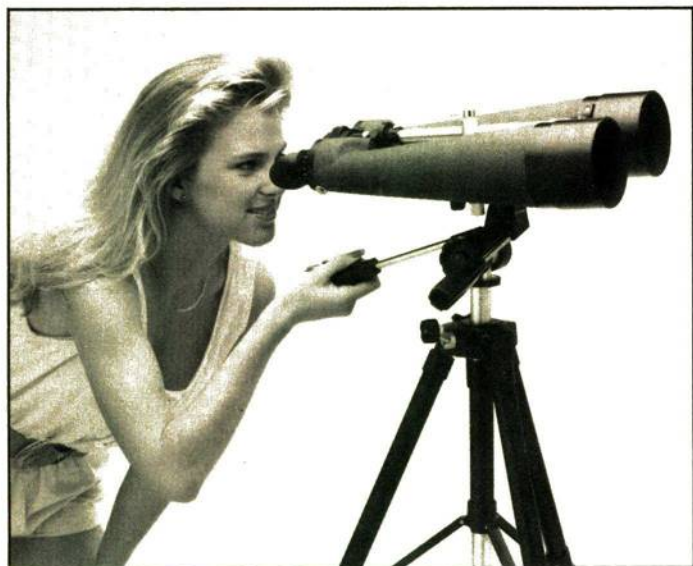
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Top: Left-to-Right: Polarizing filter set, filter adapter and reducing bushing. Bottom: Eyepiece filters.

A Polarizing Filter Set is offered for variable-density usage. Operation is easy, you need only rotate the eyepiece. The Filter Adapter is a useful accessory allowing you to use these filters with any 1¼" eyepiece. It also allows you to utilize the same filter with different magnifications more easily. The Reducing Bushing allows you to use 1¼" eyepieces and these filters with instruments normally using .96" eyepieces.

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The Triumphant Grand Tour of *Voyager 2*

To get close-up shots of Jupiter, Saturn, and Uranus, scientists on Earth corrected problems on *Voyager 2* in mid-flight.

by Mark Littmann

Editor's note: The flight of NASA's Voyager 2 to the outer planets of our solar system reaches its final destination next August when the spacecraft flies by Neptune. The scope of the discoveries made by Voyager 2 at Jupiter, Saturn, and Uranus are awe-inspiring; the technical skill of the engineers and programmers who have kept Voyager 2 going for over a decade is no less impressive.

This is the story of the mission's beginnings and the tribulations it has endured during what may well be the greatest expedition of discovery mankind has ever undertaken.

Only once every 175 years do the outer planets align themselves so that a spacecraft can, with minimal fuel, use the gravity of one planet to change its course to another, and repeat that process twice more so that four successively more distant planets can be reached. Space engineers and scientists can squeeze four planetary visits out of one space probe — if that craft can last more than twelve years and still function in an environment where diminishing sunlight plunges the temperature toward 400 degrees below zero Fahrenheit.

On August 20, 1977, America's *Voyager 2* space probe rode a Titan-Centaur rocket away from Earth on a trajectory that could carry it by Jupiter in such a way that the largest planet's gravity would sling the craft on to Saturn. With care, it would have the right path so that the gravity of Saturn could, in turn, hurl the vehicle toward Uranus. Again, with just the right position and time of encounter, *Voyager* could use the gravity of Uranus to venture on to Neptune. It was a Grand Tour of the four largest planets in the solar system.

The *Voyager 2* Grand Tour mission to four planets almost didn't happen — three times.

The opportunity began to take shape in 1965 with discoveries by Gary Flandro and Michael Minovich that the gravity of the giant planets could be used to change

the speed and course of a spacecraft so that it could fly on to a new destination. Specifically, Flandro determined, a spacecraft could use the gravity of Jupiter to accelerate on to an outer world with little or no further expenditure of fuel and with a great savings in time.

"The work that led directly to the 'Grand Tour' began at the Jet Propulsion Laboratory in Pasadena in 1965," according to Flandro. "My supervisor was Elliot 'Joe' Cutting, with whom I had worked earlier on some trajectory problems. Joe assigned me the task of identifying possible unmanned missions to the outer planets. That was quite a leap at a time when America's longest spaceflight had been *Mariner 4* to Mars. The mere thought of missions to Saturn and beyond caused spacecraft engineers to tremble. The great distances to those bodies required long flight times. Missions that required vehicles to perform flawlessly for nine years or longer were thought to be beyond our technical capability.

A New Realization

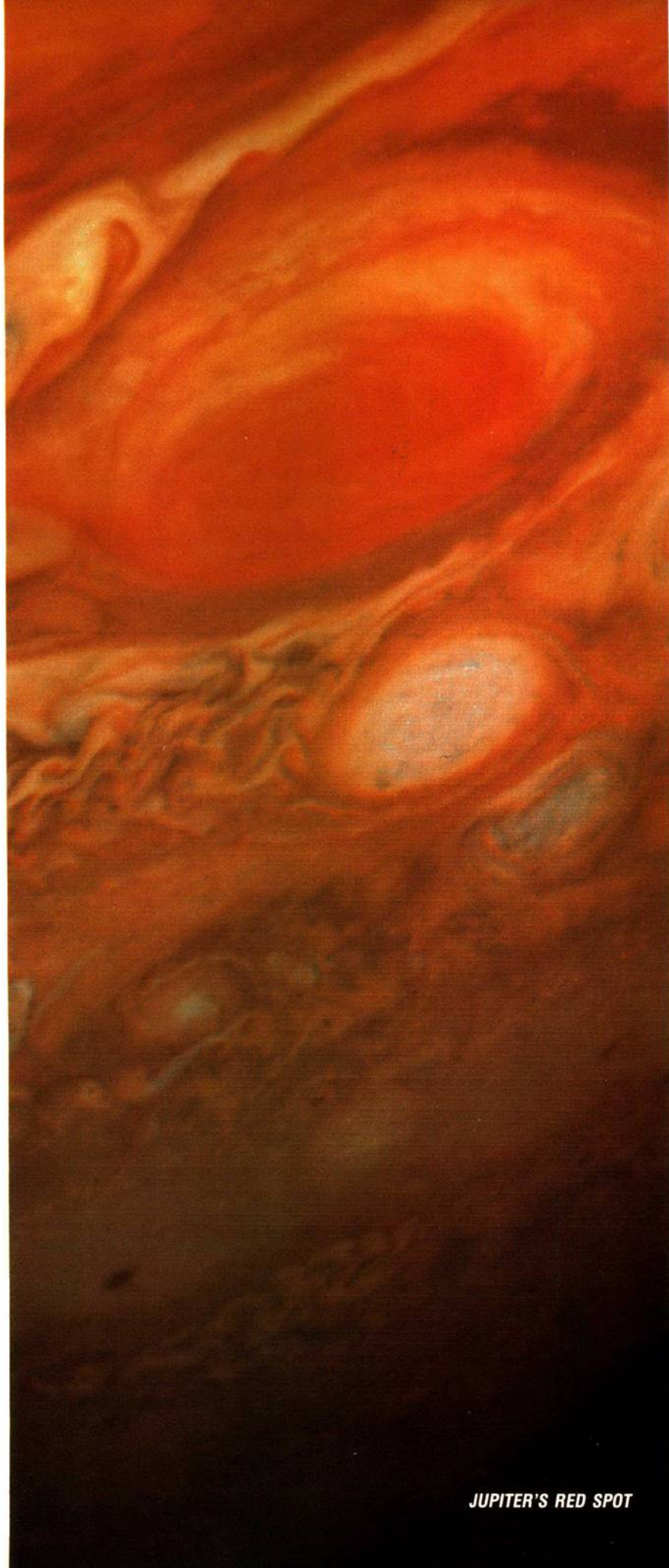
"It was a great challenge to make exploration of the outer planets practical. I examined the conventional spaceflight trajectories to reach an outer planet with the least energy expended, in which a space-

craft is treated as a miniature planet in orbit around the Sun. The vehicle's perihelion is the Earth's orbit, its aphelion is the target planet's orbit, and the flight is timed so that the spacecraft will arrive at the target planet's orbit just as the planet itself reaches that position. For trips beyond Jupiter, the flights took too long. We needed more speed, but we could accelerate the payload in a major way only during the rocket burn following launch. After that, a spacecraft bound for the outer planets constantly loses speed because of the Sun's gravity. Was there some other energy source that could be tapped en route to increase the speed of the spacecraft? That was the key realization.

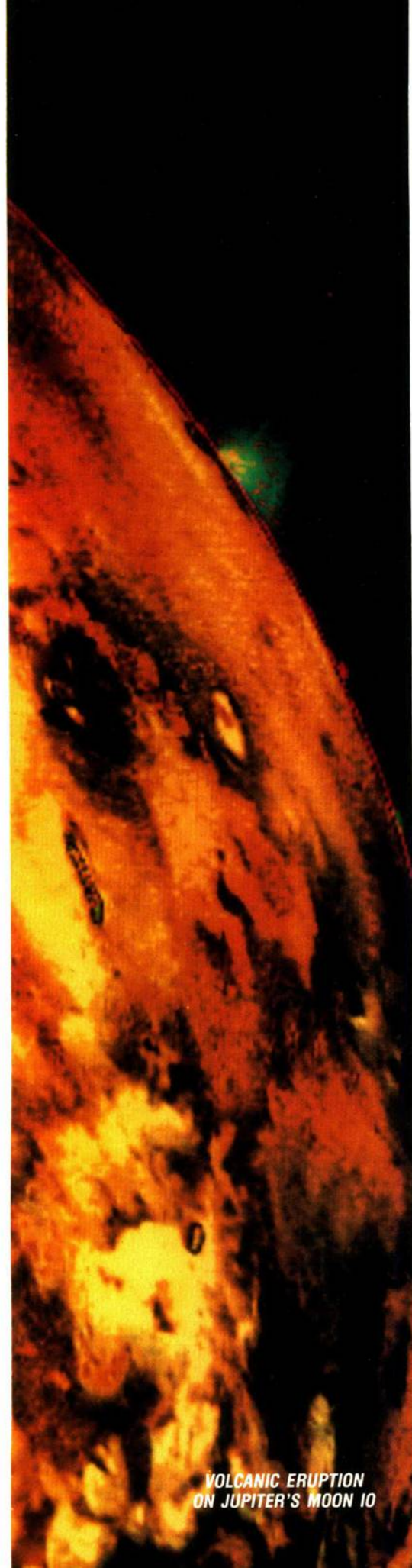
"Astronomers had known since the late 1600s that when a comet passes close to a massive planet like Jupiter, its kinetic energy is changed tremendously and its orbit is greatly perturbed. Spaceflight pioneers understood this but did not realize its potential. The earliest study of 'indirect' trajectories that used intermediate planets to mold the flight path in a desirable way was

**The *Voyager 2*
Grand Tour mission to
four planets almost
didn't happen —
three times.**

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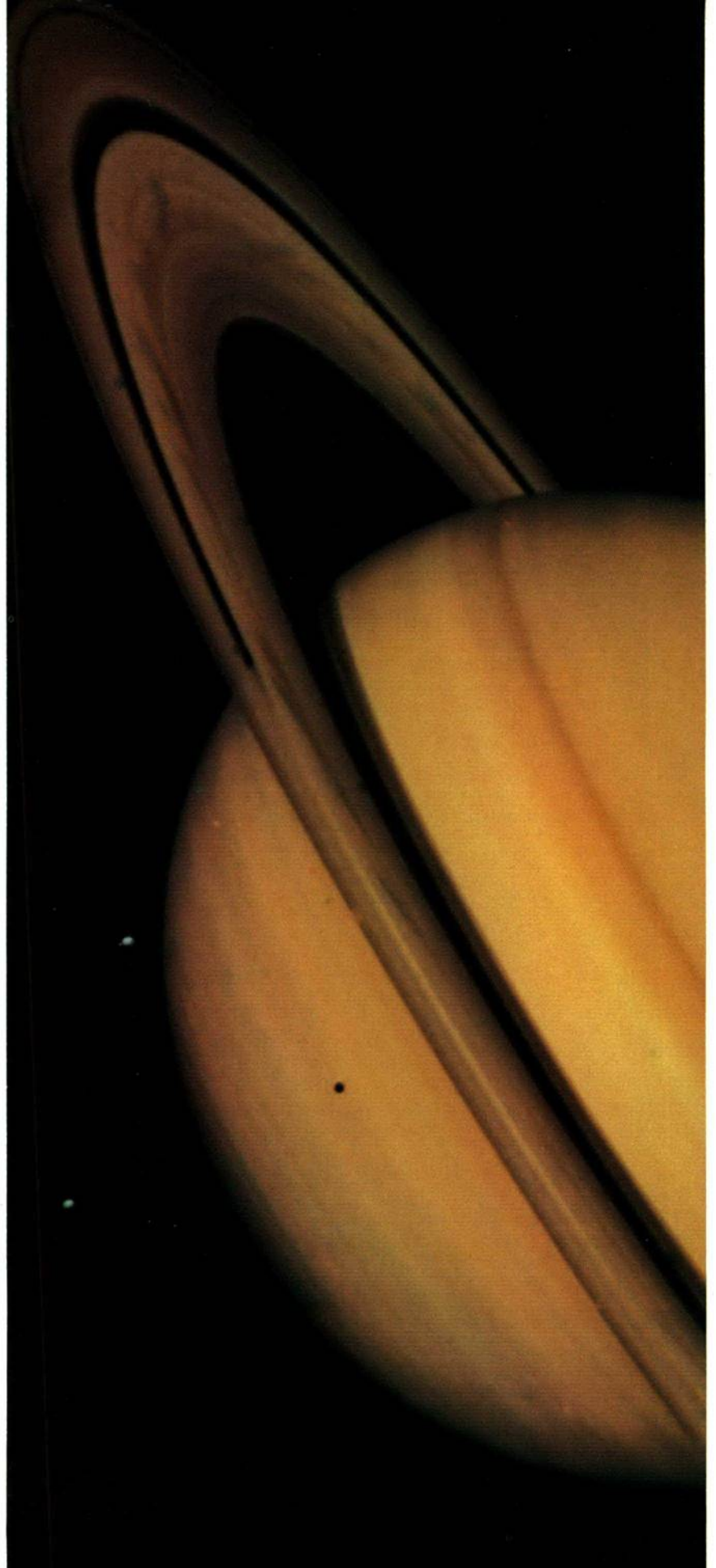
JUPITER'S RED SPOT



VOLCANIC ERUPTION
ON JUPITER'S MOON IO



SATURN'S MOON MIMAS



SATURN

by Walter Hohmann in his book *Die Erreichbarkeit der Himmelskörper* (The Accessibility of the Celestial Bodies), published in 1925.

"Scant attention was paid at first to such trajectories in the technical literature on spaceflight. By 1965, however, JPL investigators were examining 'gravity-assist' flight paths. Joe Cutting and Francis Sturms had devised a trajectory to the innermost planet Mercury that used a flyby at Venus to drop the spacecraft in toward the Sun. This concept became *Mariner 10*, the first successful multiplanet mission.

"Also working on gravity-assist possibilities that summer at JPL was Michael Minovich, a UCLA graduate student in astronomy. He was studying trajectories that used close flybys of Jupiter for the purpose of either escaping the solar system or making close approaches to the Sun. If a spacecraft caught up with a planet from behind, it gained energy and was flung outward at an increased speed instead of returning to the inner solar system on its original elliptical trajectory. If a spacecraft crossed in front of a planet, it lost energy and fell closer to the Sun. Joe Cutting suggested that I examine gravity assist as a means for reaching the outer planets.

"Strange as it now seems, many JPL engineers had misconceptions about gravity assist in 1965. They knew that because of gravity a spacecraft would gain speed as it approached a planet and lose speed as it coasted away, but they thought that there would be no net change in the spacecraft's energy relative to the Sun. They failed to consider that the planet was in motion around the Sun and could itself lose energy as it accelerated the spacecraft.

"It became clear to me that the key to the outer solar system was to utilize the gravity-assist method. It was also obvious that Jupiter, with its enormous mass to bend spacecraft trajectories, was the best energy supply station since its distance was reasonable, requiring typically a two-year flight time."

Discovering the Grand Tour

Most fascinating of all, Flandro found that the outer planets would be positioned in 1977 for a four-planet trip. A standard rocket journey direct from Earth to Neptune without gravitational assist would have required forty years. The Grand Tour, as Flandro named it, would allow a spacecraft to visit the four giant planets in twelve years.

"It was at this time," said Flandro, "that I discovered something that had apparently not been noticed earlier: in the early 1980s, all of the outer planets would be on the same side of the Sun and in amazingly close proximity. This conjunction of the outer planets provided the inspiration for the Grand Tour mission concept. I could see immediately that a single spacecraft could explore all four giant outer planets by using each planet in succession to modify the spacecraft's trajectory as necessary to rendezvous with the next planet in the series.

"This was a rare moment of exhilaration. I immediately began work to determine if practical multi-outer planet trajectories could be located. It took about a thousand trajectories to map out the original mission profiles

and launch dates for the Grand Tour. The best launch window was in September 1978, with acceptable windows in 1977 and 1979.

"I was asked to present the Grand Tour concept to Homer Joe Stewart, one of my professors at Caltech who also worked at JPL as director of the advanced concepts group. He saw the potential instantly. The very next day, JPL issued a press release describing the Grand Tour to the outer planets. Serious consideration of a multi-outer planet mission at JPL had begun."

But there was a severe constraint. Could a spacecraft be built in time to take advantage of this rare planetary lineup? The challenges were formidable. In 1965, man had not yet walked on the Moon. Only one spacecraft, NASA's *Mariner 4*, had reached as far as Mars. To fly a twelve-year mission so far from the Sun would not just stretch capabilities, it would require the development of new technologies.

With substantial power needs and yet sparse sunlight in the outer solar system, it would not be possible to use solar panels to provide electricity for the spacecraft. Instead, the project would require miniature nuclear generators. At such great distances from Earth, the spacecraft's onboard computer would have to recognize and handle emergencies since radio communication with the Earth would require hours. Finally, the spacecraft systems and scientific instruments would have to last at

least twelve years — a duration of time that in 1965 was longer than the space age was old.

As daunting as the challenge of the Grand Tour was, the problem of Congressional approval was greater. The mission was canceled in December 1971. Most of the technical problems of a Grand Tour had been solved — Pluto had even been added to the itinerary — but Congress balked at a price tag of nearly \$1 billion.

A Somewhat Less-Grand Plan

In the summer of 1972, Congress voted \$360 million for a less ambitious project: a flight to Jupiter and Saturn by two probes patterned after the *Mariners* that had successfully flown past Mars and Venus. The Jet Propulsion Laboratory would be the lead center for the project.

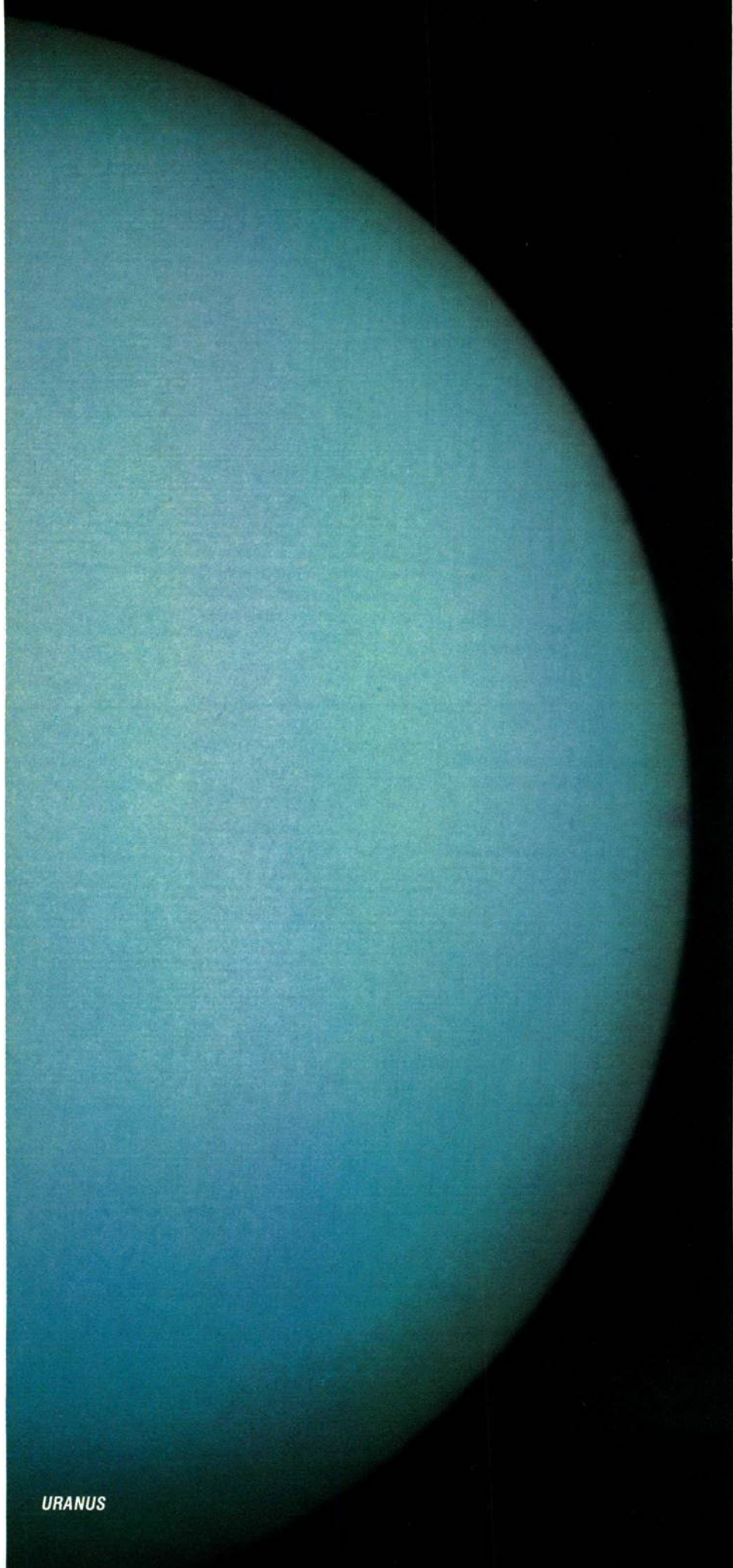
The shorter two-planet flight required spacecraft designed for only a four-year mission — not twelve. The *Mariner* Jupiter-Saturn project would use a gravitational assist at Jupiter to reach Saturn, but the Grand Tour mission to encompass four planets was dead.

Almost, but not quite. NASA began plans for a third *Mariner* probe to be launched on a Jupiter-Uranus mission in 1979. In 1975, the Jupiter-Uranus project and the third spacecraft were canceled for lack of funds.

In 1977, the *Mariner* Jupiter-Saturn project was given a more manageable name — *Voyager*. And the *Voyager* management team took a final fond look at the Grand Tour plan. The highest priority objectives at Jupiter and Saturn included not just data from the planets but also close-up pictures and measurements of Jupiter's innermost large moon Io and Saturn's largest moon Titan.

It was still possible with a 1977 launch to fly the Grand Tour but only by sacrificing optimum views of Io

**A standard rocket
journey from Earth to
Neptune without gravity
assists would have
required forty years.**



URANUS



URANUS' MOON MIRANDA

and Titan. If *Voyager 1* flew suitably close to Io, it would acquire so much velocity from Jupiter that it would arrive at Saturn too soon to be diverted on to Uranus. If *Voyager 1* flew suitably close to Titan, it would leave Saturn headed in the wrong direction to reach Uranus.

But if *Voyager 1* gave up its option for a Grand Tour, it could examine both Io and Titan close up as the central mission objectives required. That would leave *Voyager 2* in a back-up position — ready to undergo mid-course correction to fill in for *Voyager 1* if it failed at Saturn. But if *Voyager 1* succeeded at Saturn and Titan, *Voyager 2* could broaden the coverage at Saturn as it would at Jupiter while maintaining course for a Grand Tour mission on to Uranus and Neptune.

The flight to Uranus and Neptune, already twice canceled, was on again. It required no extra money, at least not immediately. It was only a contingency plan. A hope. A dream.

Voyager 2 was launched first, on August 20, 1977. *Voyager 1* lifted off on September 5, 1977, on a slightly more direct and hence faster route so that it would reach Jupiter and Saturn ahead of its sister ship. But project managers still considered a successful Grand Tour a long shot.

Voyager 1 succeeded brilliantly at Jupiter. It documented in detail the turbulent flow of the Jovian atmosphere, especially near the Great Red Spot, a centuries-old storm that is at least twice the size of Earth. *Voyager 1* found that Jupiter has a faint dusty ring. At Jupiter's moons, *Voyager 1* discovered active volcanoes on Io, the surface of Europa covered by cracked ice, parallel ridges and grooves on Ganymede, and a surface on Callisto so heavily cratered that new impacts erase as many craters as are formed.

Voyager 1 again performed splendidly at Saturn. The fabled ring system was composed not of a few but of thousands of rings. Winds in Saturn's atmosphere reached speeds of 1,000 miles per hour. Among Saturn's moons, Titan was known to have an atmosphere. *Voyager 1* found that this atmosphere was denser than Earth's and that its principal constituent was nitrogen. *Voyager 1* revealed for the first time details on the other moons of Saturn, a wild variety of terrains with abundant evidence that, despite their modest size, these worlds had experienced internal evolution long after formation.

On August 25, 1981, *Voyager 2* successfully cleared Saturn on course. The Grand Tour was on. On — but threatened, this time by problems with the spacecraft.

A few months after *Voyager 2* set out for Jupiter, one of its radio receivers, vital for the spacecraft to receive instructions from Earth, failed outright and the back-up receiver lost its tuning ability. As it flew by Saturn, the *Voyager 2* scan platform, which turns the cameras and some of the other scientific instruments toward their targets, seized up. Throughout most of the mission outward, a small portion of the spacecraft's computer memory has been inoperable.

Yet by the time it reached Uranus on January 24, 1986, after an eight-and-a-half-year flight, *Voyager 2* was a better spacecraft than when it left home. The Jet Pro-

pulsion Laboratory scientific and engineering team had redesigned the spacecraft in flight.

Repairs via Long Distance

Seven-and-a-half months after launch, en route to Jupiter, a power surge on *Voyager 2* permanently destroyed the primary radio receiver and damaged the back-up so badly that it could not tune to different frequencies from Earth. Before the failure, the receiver had been able to scan across 100,000 hertz and lock onto a signal. That was necessary to compensate for the varying wavelengths caused by the Doppler effect as the spacecraft moves away from Earth at varying speeds. Because of gravity, the spacecraft's speed gradually increases as it approaches a planet or moon and gradually slows down after passing it. The receiver's scan/lock-on feature was also necessary to compensate for variation in receiver temperature, which alters what wavelengths the radio can receive.

After the power surge aboard *Voyager 2*, the tiny remaining range of frequencies that the receiver could accept was only ± 96 hertz. The bandwidth for reception had been cut a thousandfold. A change of 0.5° F was enough to render the spacecraft deaf. This problem was severe and scary. Without the ability to update the spacecraft's instructions, the mission was lost.

The flight team solved the problem by carefully adjusting the transmitted wavelengths to compen-

sate for the Doppler effect and expected temperature so that *Voyager 2* could receive all its messages within a single small bandwidth, the only frequency it could hear. The flight team would transmit to *Voyager 2* only when the craft was in normal cruising mode. After spacecraft maneuvers that generate heat within the probe, the flight team would wait forty-eight hours before sending messages to *Voyager 2*.

This radio reception problem meant that *Voyager 2* would be deaf to Earth commands during the close phases of the Uranus and Neptune encounters. No matter. A message from Earth to *Voyager* at Uranus and a confirming message from *Voyager* to Earth required five-and-a-half hours — almost the entire length of the *Voyager 2* close encounter with Uranus. The spacecraft would have to be very carefully preprogrammed without error with instructions for the entire close-in data-gathering and picture-taking sequence at Uranus and Neptune in order to enjoy a successful flyby.

The technical challenge of getting good information from Uranus was intimidating. Uranus lies at twice the distance of Saturn, so there is only one fourth as much sunlight at Uranus to provide illumination for pictures. Thus long exposures are necessary. But long exposures of moving objects lead to smeared images unless the camera is moved to track the target.

Unfortunately, the scan platform on which *Voyager 2*'s cameras were mounted had jammed as it pivoted rapidly to follow targets one-and-a-half hours after its closest approach to Saturn. A number of pictures and measurements scheduled to be made were lost because the spacecraft could not point its instruments in the right direction. Lubrication gradually seeped back into the gears and the system seemed to be working again at

By the time it reached Uranus, *Voyager 2* was a better spacecraft than when it left home nine years before.

slow and moderate speeds, but the mission team wanted to take no chances. So whenever fast or even moderately fast slews were required of the scan platform to track the targets, the entire spacecraft was rolled to follow the action. Rolling the entire craft provided smoother motion besides. But it was tricky. *Voyager 2* would rush by the moon Miranda at twenty times the speed of a rifle bullet while the whole spacecraft rolled to pan its camera to an accuracy of better than 0.1° .

Sending Pictures Quicker

As *Voyager 2* sped farther from Earth, its radio signal became weaker. At Jupiter, the signal was weak but adequate. At Saturn, almost twice as far away, the signal was four times weaker. At Uranus, more than twice the distance of Saturn, the signal upon which all the data would be received on Earth was four times weaker than from Saturn and sixteen times weaker than from Jupiter. The result was that in order to avoid a jumbled message, *Voyager 2* could not pack its data so tightly for transmission, just as a speaker talks more slowly to make certain he is understood.

Especially critical were the images to be transmitted, which required vast amounts of transmission time. All *Voyager* pictures are black and white, but taking multiple pictures through filters allows scientists back on Earth to combine filtered pictures to make color images. Even so, transmitting black-and-white pictures requires enormous quantities of bits. Each *Voyager* image is a television picture formed from 800 pixels (picture elements — dots) across and 800 pixels down — a total of 640,000 pixels. And the darkness or lightness of each of these pixels is described by 8 binary bits to provide a gray scale of 256 shades. Thus each picture to be transmitted required $640,000 \times 8 = 5,120,000$ bits of information — over 5 million bits.

At Jupiter, *Voyager's* X-band transmitter could start and finish broadcasting a picture to Earth within forty-eight seconds. At Uranus, the transmission time for a single image would rise to ten minutes — unacceptably long. When *Voyager* rolled so that its camera could track a target, its antenna would be turned away from Earth and its tape recorder would store the images until they could be transmitted. With transmission times so long, there was danger that the recorder would be quickly overwhelmed and precious pictures and other data would be lost.

The computer scientists at JPL came up with a solution — a computer innovation called data compression. Instead of describing the exact shade of gray of each pixel in an image, only the first pixel in each line would be precisely described. Each pixel that followed in that row would then be described only in terms of how much lighter or darker it was than the one preceding it. The data compression system reduced the number of bits required to send an image by 60 percent. Instead of twelve minutes to broadcast one picture from Uranus, it would now take only five.

But data compression was not the only improvement to *Voyager 2* made en route to Uranus. *Voyager* engineers also worked out a new system for shorter bursts on the thrusters to stabilize the craft, making it

smoother in its maneuvers. *Voyager 2* became able to take steadier pictures while becoming more conservative of fuel.

So as *Voyager 2* got older, it actually got better, because of the ingenuity of a lot of scientists and engineers on Earth.

Hearing Voyager's Faint Voice

And facilities on Earth improved as well. They had to if they were going to hear the puny radio signal of *Voyager* all the way from Uranus. "Clear channel" radio stations in the United States broadcast on 50,000 watts of power. *Voyager 2* transmits its data to Earth on 22 watts. But that signal spreads out during its journey from Uranus so that by the time it has traveled 1.75 billion miles, a 210-foot dish receiver on Earth captures only one billionth of one millionth of a watt.

To receive *Voyager 2's* information from Jupiter and Saturn and to transmit instructions to the spacecraft,

NASA had used its Deep Space Network — three tracking stations scattered a third of the way around the world from one another. One is at Goldstone, California, one hundred miles northeast of Los Angeles. The second is near Madrid, Spain. The third is near Canberra, Australia. Each Deep Space Network site was equipped with a steerable parabolic dish antenna 210 feet in diameter.

For the Uranus encounter, those dishes weren't enough. NASA augmented its receiving capability by linking the giant dishes to smaller dishes at each station. It worked like an old-fashioned ear horn for a partially deaf person: the more receiving area, the more signal captured. The timing of the encounter placed the greatest burden on the Canberra and Goldstone sites. There, two 112-foot antennas were arrayed with the 210-foot dish. At Canberra, the receiving site for *Voyager's* data at closest encounter, a further enhancement was made. The Australian government linked its 210-foot Parkes radio telescope with the three-dish array at Canberra.

It had taken four-and-a-half years for *Voyager 2* to fly from Saturn to Uranus. Working against formidable obstacles of distance, darkness, and planetary orientation at Uranus; working against a crippled radio receiver, a sticky scan platform, and a degraded computer on board the spacecraft, every aspect of the Uranus encounter had to be meticulously planned so that *Voyager 2* could take full advantage of the first opportunity since the dawn of the space age to examine in detail the realm of Uranus.

At Jupiter and Saturn, *Voyager 2* had been the back-up craft, following up on *Voyager 1's* discoveries and duplicating measurements from a different angle. Now, at Uranus, *Voyager 2* was the only spacecraft, traveling where no spacecraft had ever gone before.

On January 24, 1986, eight-and-a-half years outbound from Earth, NASA's *Voyager 2* spacecraft passed 50,700 miles above the cloud tops of Uranus. The data radioed from *Voyager* took two and three-quarters hours to reach home, traveling at the speed of light.

Long before *Voyager 2's* data could be fully analyzed and its discoveries thoroughly appreciated, Uranus was a starlike dot far behind the spacecraft, which was already preparing for its next and final port of call. □

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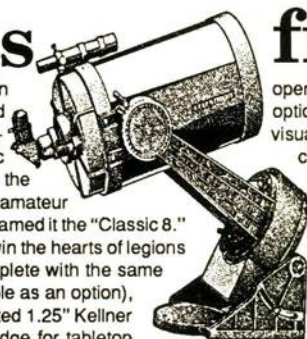
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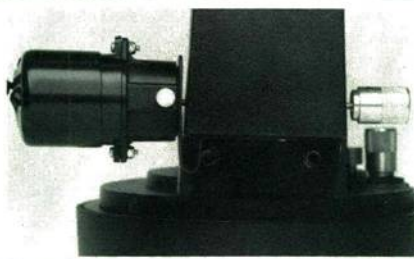
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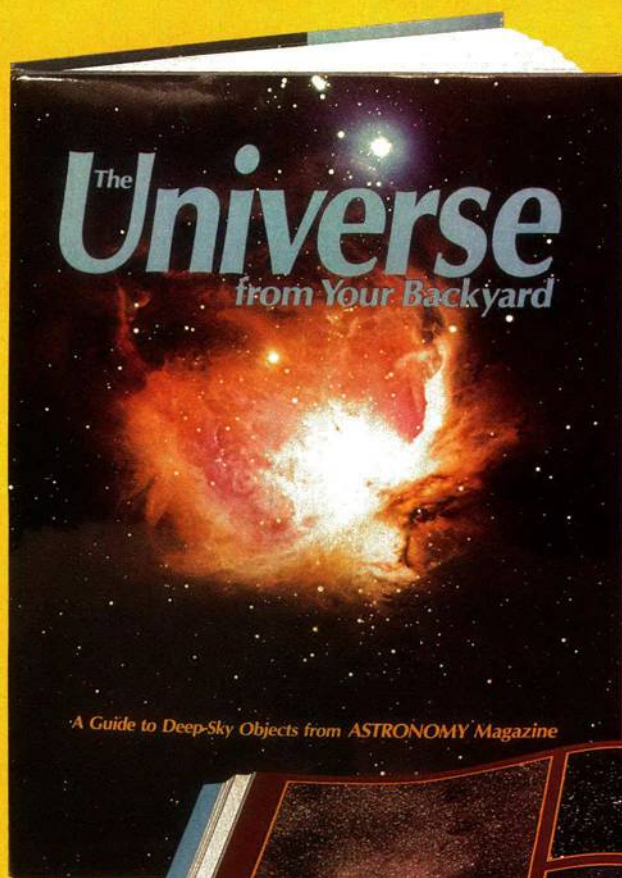
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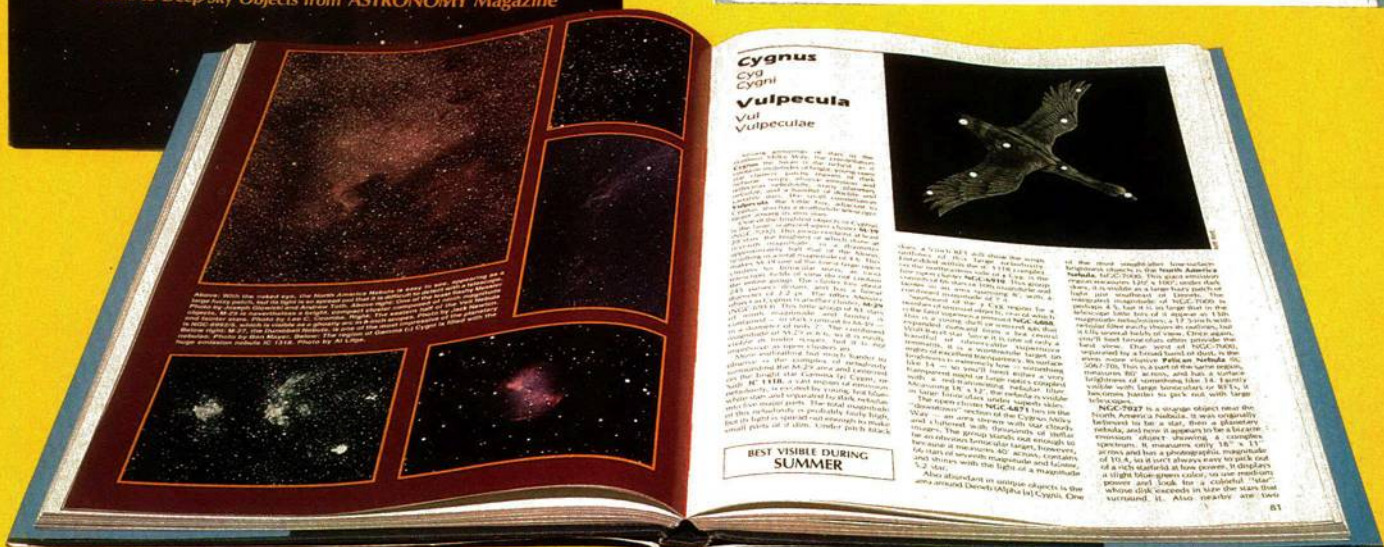
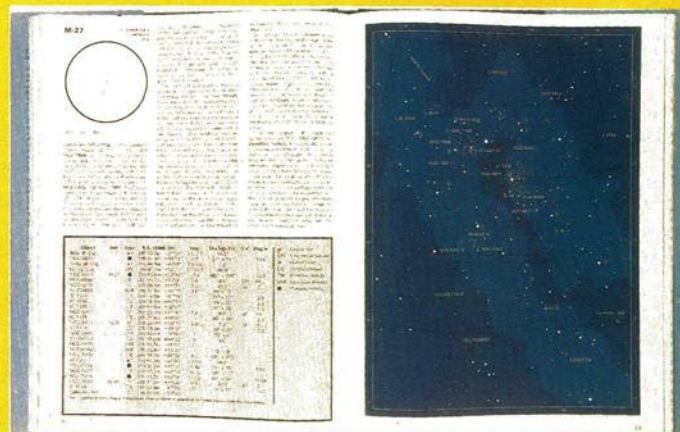
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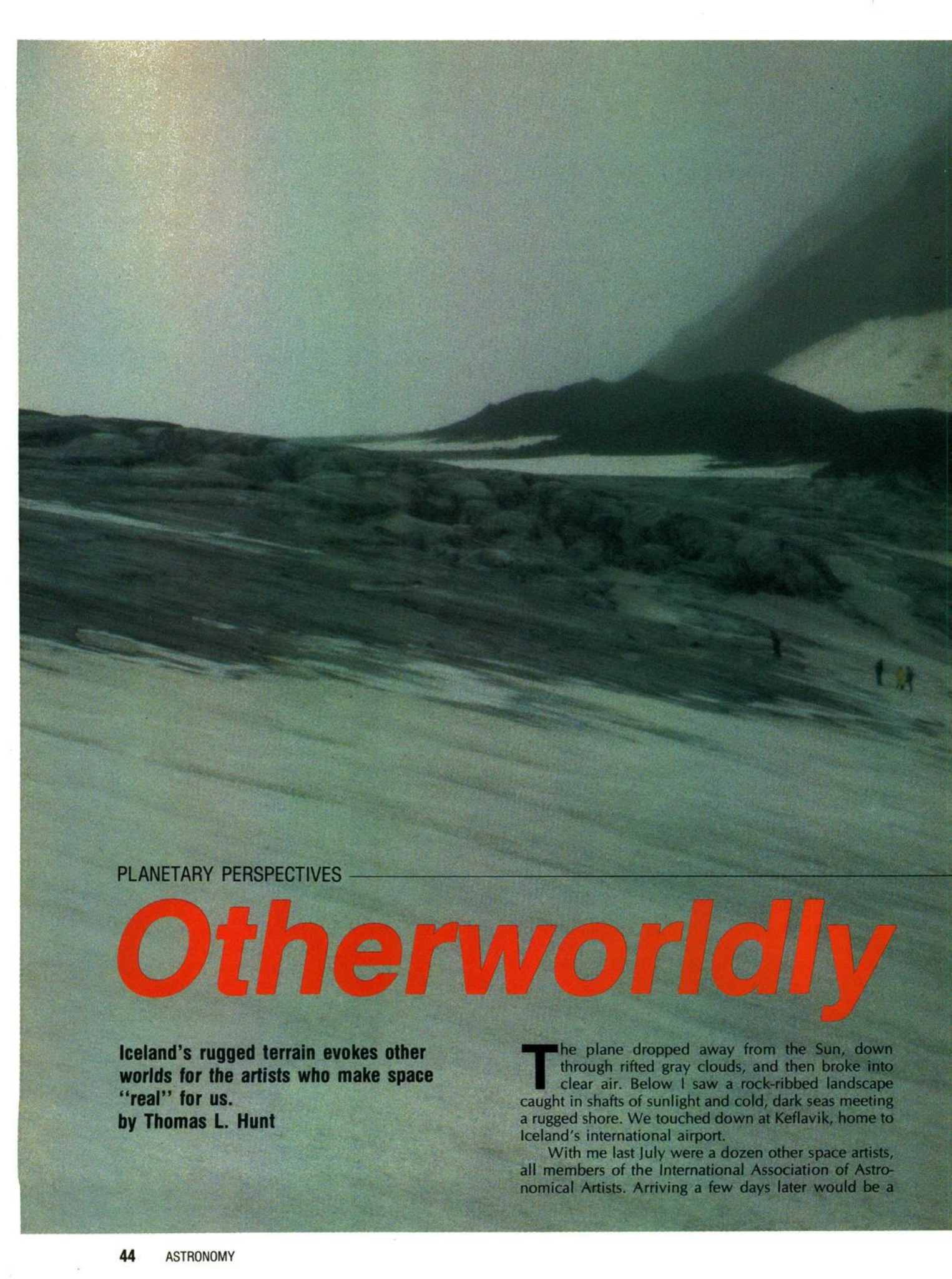
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PLANETARY PERSPECTIVES

Otherworldly

Iceland's rugged terrain evokes other worlds for the artists who make space "real" for us.

by Thomas L. Hunt

The plane dropped away from the Sun, down through rifted gray clouds, and then broke into clear air. Below I saw a rock-ribbed landscape caught in shafts of sunlight and cold, dark seas meeting a rugged shore. We touched down at Keflavik, home to Iceland's international airport.

With me last July were a dozen other space artists, all members of the International Association of Astronomical Artists. Arriving a few days later would be a



Visions

group of Soviet space artists, with whom we would travel and explore. We had told friends and spouses we were going to Iceland to hold a workshop, but this wasn't completely true. In reality we had come here to go to Mars or to the Moon — just as *Apollo* astronauts came here more than twenty years ago to practice lunar geology. In this exotic land we hoped to see, sketch, and paint landscapes that were close to those found on other planets.

A space artist is someone who is bucking a long-standing trend: art and science have grown so far apart that the gap seems all but unbridgeable. And yet art still plays a vital role in helping us see and understand — in making *real* — the strange, beautiful, and alien worlds around us. The photos from *Voyager*-type missions tell part of the story, but it takes a space artist to make you feel as if you're walking beside the miles-high ice cliffs on Uranus' Miranda or gazing across Mare Imbrium as



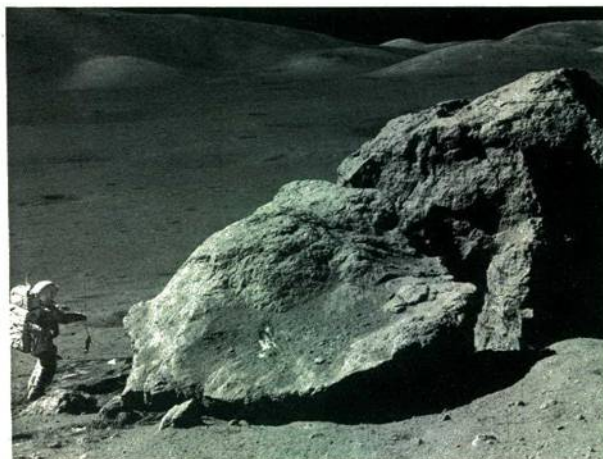
**Iceland offered us the Moon
— and Mars, and Venus, and Io,
and. . .**

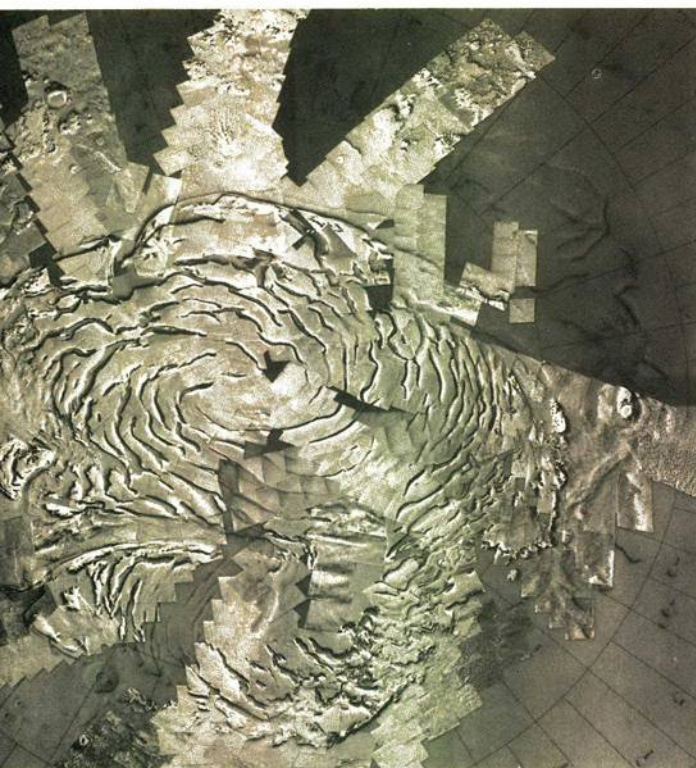


VISITORS FROM A "DIFFERENT WORLD," Soviet space artist and ex-cosmonaut Alexei Leonov (left) and Vitaly Myagkov, head of the All-Artists' Union of the Soviet Union, explore a wintry Martian landscape.



A MOONLIKE BOULDER tempts Soviet space artist Pyotr Kovalev into looking for terrestrial analogies to lunar reality (below).





AS DESOLATE AS MARS, the mighty ice-draped volcano Hekla (opposite page, top) offered us terrain to match Mars' polar caps. Above, the real thing.

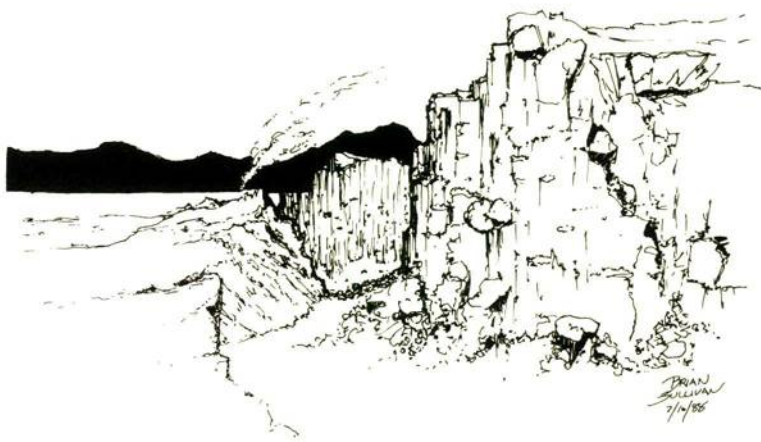
the Apennines blaze at sunset.

Astronomical artists join a long tradition of nature artists. When explorers such as Cook, Humboldt, and FitzRoy undertook expeditions into unknown lands, they brought along artists to record the findings and bring back pictures of the new and wonderful things they found. The wildlife of this continent was recorded by people such as John James Audubon and William Bartram — often self-taught but always driven by a deep desire first to understand and then to portray.

A vivid imagination is essential to any space artist, yet there is always a need to see new places, to inform and discipline the imagination. Previous space art workshops have been held on the slaggy shoulders of Mauna Kea in Hawaii, in Death Valley, and at the Craters of the Moon National Monument in Idaho. For most of us on the Iceland trip, the big trek away from planet Earth started right after we landed. As we passed cinder cones and leg-breaking, tumbled fields of black lava, the conversations on the bus drifted from the greetings of old friends to questions about what type of rock formation that was and would it occur on Mars.

Workshop plans called for two days in Reykjavik, followed by ten days in the nearly roadless (and peopleless) interior, where we traveled in a four-wheel-drive bus and stayed overnight in hikers' cabins. Many of our group were about the same age — in their thirties — and about half of them were self-taught artists. Most combined an acute eye for detail, a strong interest in astronomy and geology, and an insatiable curiosity about new places.

Dennis Davidson, a New York artist and illustrator at the Hayden Planetarium, had devised an itinerary with advice from geologists that would cover as much of the solar system as Iceland had to offer. Arizona space artist Marilyn Flynn prepared a field guide for the workshop



EARLY EARTH — OR MARS? Brian Sullivan painted the rift valley at Thingvellir as a scene from long ago — or far away.

that identified the landforms of Iceland and described their counterparts on other worlds.

We hoped to see scenes that duplicated or mimicked those on the Moon, Mars, Venus, and several of the Galilean moons of Jupiter. These ranged the full gamut from table mountains formed when a volcano erupts under a glacier to Mars' layered polar caps.

Iceland stands on the Mid-Ocean Ridge, a globe-girdling chain of undersea mountains that runs the entire length of the Atlantic like a rocky spine. Literally on the edge between the European and North American plates, Iceland is the largest part of the ridge exposed above the water surface. It is entirely volcanic except where present day sedimentary deposits are accumulating as its rocks weather.

The rift zone in the center of the Mid-Ocean Ridge cuts across Iceland from southwest to northeast. This rift zone, a collection of many parallel valleys bordered by faults, is the site of earthquakes and much volcanic activity — from vent eruptions such as that which created the new island Surtsey in 1963 to outpourings of lava such as the Laki fissure eruptions of 1783. In the latter case, many farms were covered with lava, the air was poisoned with sulfur dioxide for several months, and the country lost about a fifth of its population and most of its livestock because of famine and disease.

Like all of the other artists, I found Iceland to be a powerfully affecting experience. You feel totally surrounded by "Earth-energy": something was always bubbling, gurgling, or rumbling — if not literally underfoot, then on the other side of a valley. In places the ground shook and nature's powers seemed barely held in check.

Most of us had trouble sleeping, in part because the Sun was up for almost twenty-four hours but also because the scenery was overwhelmingly beautiful. It wasn't hard to reach a state of sensory overload. I think every one of us skipped at least one side trip so we could spend a day indoors. We said it was to get impressions down on paper, but it was also a relief just to collect our thoughts.

As we walked up the Eldgja rift valley, Ron Miller said, "Now I know what it's like to walk in Vallis Marineris." The valley contains one of the best examples of Mars here on Earth — rugged terrain, steep slopes cut-



TRAMPING "VALLIS MARINERIS" under a threatening sky gave us all the spooky feeling of being alone on a desolate planet.



CLOWNING AROUND at Lake Myvatn are Alexei Leonov (in the opening) and Georgiy Orlov.



MARCHING COLUMNS OF BASALT offer Georgiy Orlov a view of alien terrain.



MARTIAN FAULT VALLEYS take on reality as Bill Hartmann and Marilyn Flynn study Lake Myvatn.



ARTIST'S CURIOSITY prompted Pamela Lee to see what glaciers look like from the inside.



We climbed the rocks, explored the crevasses, and talked of other worlds.

ting off distant views, and utter desolation everywhere you looked. Even the penetrating mist and low-hanging clouds, although completely un-Marslike, nonetheless helped create the spooky feeling of being alone on another planet.

Elsewhere in the rift valley you can walk next to chains of craters like those found on the Moon, Mars, and Callisto. (Unfortunately the swirling mists hid them.) But, leaving the valley, we crossed a field of pseudocraters that took us to Acidalia Planitia in the northern wastes of Mars. Pseudocraters look like real craters, but they aren't caused by impact and they don't surround volcanic vents. They occur instead when fresh lava flows across ground saturated with water. Underneath, the water flashes to steam and escapes explosively where the lava layer has thin spots, building roundish rings of tephra — sharp cinders, large and small blocks, gravelly stuff — often with a pit in the center.

We acted like kids let out of school as we ran up and down the sides of these things. You stand on the rim of one and see dozens more surrounding you. A *Viking* orbiter photo shows a field with what could be the same features in part of Acidalia. The craters were covered in thick green moss — it was probably the greenest place we saw in Iceland — but their shapes were distinct and it took only a little imagination to envision ourselves on the Red Planet.

At another site, Myvatn, a lava flow had surged into a lake and its pseudocraters showed different colors where the tephra was stained by sulfur deposits. William K. Hartmann, a planetary scientist by profession and a self-taught space artist, commented that painting the place was like doing Mars: "The oxidation on Mars really shortens the palette. Everything is in shades of yellow-orange. You can do it, but you have to make it really subtle."

At Thingvellir in the southwest, the rift is about four miles across and two hundred feet deep. Hartmann explained that this fracturing, where the ground between two parallel faults drops to create a landform called a



SCRAMBLING ACROSS VENUS, artists scout out formations that resemble those on the real planet's surface (above).

graben, is the same type of activity that occurs at Ceratulus and Memnonia Fossae on Mars. There, hundreds of parallel ridges, up to two hundred miles in length, run radial to the huge Tharsis volcanic region.

We know from *Viking* images that the Martian polar cap is layered: bright strata of ice (both water and carbon dioxide) alternate with darker bands of dust. In the region around the great glacier-capped volcano Hekla we found many places where layers of ice alternated with those of volcanic ash, mimicking the Martian polar caps. The fact that cold rain washed over us now and then just added to the polar feel of the place!

Another Martian landform came into sight when we spied an ice chunk that had slid into a valley. This microglacier was covered by a thick layer of mud that flowed down on top of it as it sat there in the riverbed. When the ice slowly melted, it formed a small cone of mud with an icy core. This feature is called a pingo, and much larger versions of them are suspected in Acidalia Planitia.

Nearby we also saw "patterned ground," polygonal arrangements of loose rocks that develop naturally on undisturbed ground that freezes and thaws repeatedly. This brought to mind similar scenes the *Viking* cameras photographed on Mars' wintry northern polar plains.

In the outwash at the base of our little glacier we found a visual analogue of a streamflow very evident on Mars. It had channels, linear grooves, and teardrop islands where the waterflow had divided and come together many times. Looking at it, you could imagine peering down on Lunae Planum as you came in for the landing on the first expedition to Mars.

Apart from its glaciers, Hekla is an active volcano that erupts periodically, opening up along a six-mile fissure and covering the land around it with black devastation. We all understood why lunar-bound astronauts had trained here. The tephra covering the ground is deep black and rough. Next time I think of walking on the Moon, I'll think of Hekla. It was desolate — even by Icelandic standards. *Nothing* grows here.

At Thingvellir, Hekla, and Myvatn we found fissures that were visually similar to the fracture zones on Jupiter's Europa. The mechanisms were different, because Europa's surface "geology" is mostly ice (and its fractures cover a much larger scale) while Iceland's cracks and fissures are rocky. But, again, we could place ourselves mentally on an alien moon and see how parts of the landscape would translate into off-planet scenes.

Dennis Davidson got a little too close to "Europa" on the glacier Tungnaafellsjökull. A few minutes after three of us had peered over the edge of one of the crevasses on the glacier, he stepped onto the same spot where I had been looking. Davidson quickly broke through the snow and started to disappear. Our guide grabbed him just in time.

Six days into our trek the group of space artists from the Soviet Union caught up to us and our otherworldly



RETURNING FROM MARS, Brian Sullivan crosses a lava flow at Lake Myvatn. At right, the real thing — Utopia Planitia.



interests took on an international dimension. Alexei Leonov — the first man to walk in space, commander of the *Soyuz* craft during the Apollo-Soyuz Test Project joint flight in 1975, and an excellent space artist — was the unofficial captain of Soviet group. He spoke English pretty well and loved to tell stories and jokes. An amateur mycologist, he went on a mushroom-hunting expedition one afternoon and, having smooth-talked his way into the kitchen, prepared a delightful meal for us with the mushrooms.

Before we left Reykjavik, Michael Carroll — a wiry, high-energy artist at the San Diego Planetarium — had explained about protocol and the social and art style differences we would encounter. (He had met most of the Soviet artists the year before on a trip to Moscow.) He admonished us, saying, "We have a lot of importance thrust on us because we are crossing into the international world of politics." In the same spirit and because it was taking us all to Mars, Mike dubbed our backcountry bus the PHO BUS after the present Soviet mission to Mars.

After the Soviets arrived, and despite some language difficulties — there were about twenty-five of us and two interpreters — we found, to no one's great surprise, that art provides a common bond between artists. Even when you have to communicate with hand gestures and a dog-eared Russian-English dictionary, the important things get across the language and cultural barriers.

One day five of us (three Americans, two Soviets) played hooky from one of the group excursions. As Bill Hartmann put it, "I just *has* to have some painting time." We were trading techniques and critiquing our works in progress, even as far as discussing national styles of art, despite the language difficulties.

Iosef Minsky, a Soviet artist who could also speak French, stayed behind with us. He had an impish smile that told me this guy loved life. The two of us played a practical joke on Ivan Lubennikov, the other Soviet artist who stayed behind. Ivan had the misfortune to snore when he took a nap, so we tape-recorded him and Iosef played the tape at that night's round of toasts.

Iosef's main concern, besides painting (which he did



THE FAMOUS "PHO BUS" halts to let out a party of sketchers in a glaciated wasteland near Nyidalur.

every chance he got), was the relationship between the two groups. With one simple statement he said it all. He raised his hand and said "ART" with a smile. Then, frowning, he dropped his hand and intoned "POLITICS."

Georgiy Orlov from Leningrad crossed the language barrier by speaking English. He felt it wasn't very good — it was fine in fact, and, besides, few of us spoke a word of Russian.

He was curious to know about our lives in America. His only experience of the United States was New York, where the Soviet group had held meetings with members of the Planetary Society before coming to Iceland. He said, "America is like New York, yes? R-e-a-l interesting! But then my home is very provincial." It took all three of us Americans to convince him that America is *not* New York City.

Comparing working styles and techniques revealed some interesting differences between their group and ours. Like nearly everything in Soviet society, art is dominated by politics. Several artists told me they had Gorbachev's *perestroika* to thank for their Iceland trip. Soviet artists are slowly shaking off the effects of government-

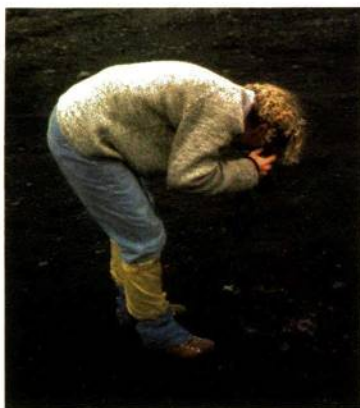


CAPTURING OTHER PLANETS on Earth is what space art is all about. Bill Hartmann (left) and Anatoly Veselov look for Mars in a lava flow at Lake Myvatn.



WHEN MARTIAN RIVERS RAN — Vatnajokull broods in the midnight twilight.

**Even small
places can
contain
un-Earthlike
vistas.**



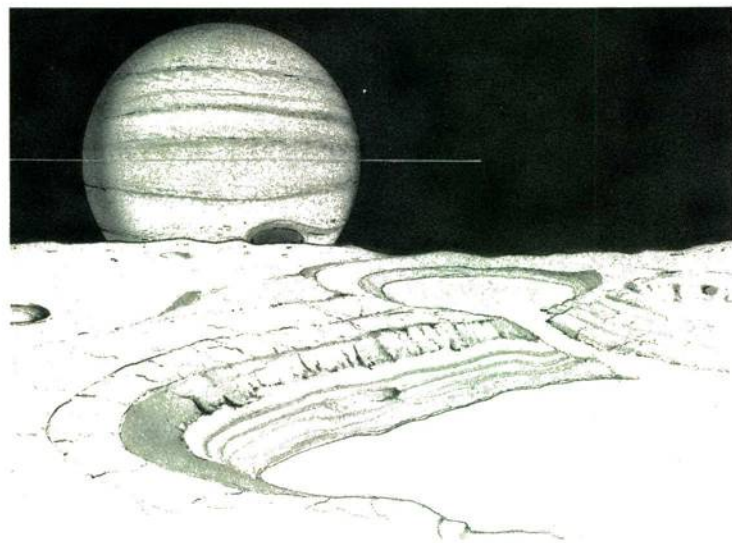
OTHER PLANETS sometimes hide away in a few square feet. Pamela Lee takes a geological note.



MOUNTAINS ON VENUS loom dark as Josef Minsky transforms Iceland into Earth's neighbor.



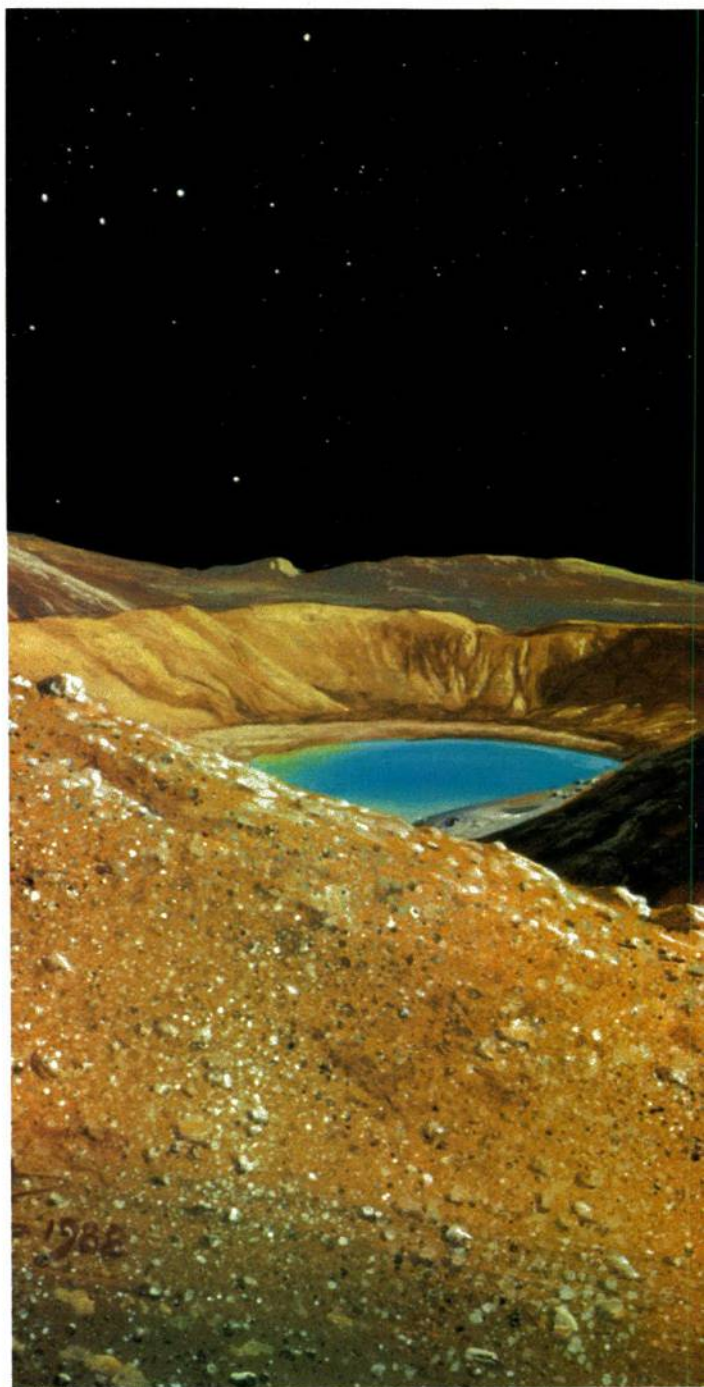
A STUDY FOR IO by Michael Carroll.



THE MUD-PITS OF MYVATN become Io, by Brian Sullivan.



IONIAN SULFUR VENTS by Thomas Hunt.



A PLACE CALLED HELL — Viti in Icelandic — becomes a landscape on Io at the hands of Michael Carroll. Below, the reality.





dictated styles of painting, mainly the socialist-realism school that in America is best seen in the public building murals done under the WPA in the 1930s and 1940s.

Soviet space artists also arrive at their profession by a different route than most Western astronomical artists follow. While a space artist in the West is usually someone who was inspired by space and then learned how to express those feelings in paint, Soviet artists train as traditional painters, become technically proficient, and then choose space as their subject. Ex-cosmonaut Alexei Leonov is an unusual Soviet artist because he followed the Western path, arriving at his artistic career later in life after pursuing a regular career in the military and space.

Iosif Minsky told me, "Our art comes from our hearts, our heads, and our land." In general, Soviet artists of all kinds work their feelings into their art more

visibly than most Western artists do. Their traditions are very humanistic: subjects are usually the betterment of mankind or focus on the theme of man conquering nature. Soviet space artists are much more likely to include human figures and usually paint in a looser and more expressive style. Westerners, on the other hand, paint moons and planets with that same obsessive attention to detail that Audubon brought to his paintings of birds, plants, and insects. I'm looking forward to next year, when the two groups get together again for a joint show in Moscow and Pasadena.

"Even though we don't have similar styles, we still respect one another's talents," said Michael Carroll, summing up our feelings as we were about to depart for home. Many of us made new friends and set up collaborations for joint projects that will bridge the gap between our two societies. But, most important, we all left with better visions of other worlds. □

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LUMICON FOR HIGH PERFORMANCE

ASTROPHOTO OF THE MONTH

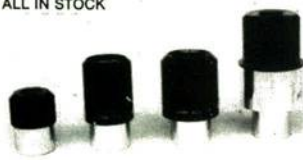


Unaided Konica SR-V 3200 Photo! Southern Milky Way over the Superstition Mountains (east of Phoenix, AZ), 2 minute unaided photo by Andre Bormanis, 28mm f/3.5, LUMICON hypered SR-V 3200.

20mm NAGLER

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Hypered 2415 film, 36 exp ... \$10.95 ... 3/\$29

DEEP-SKY ASTROPHOTOGRAPHY

SR-V 3200 NEW FILM

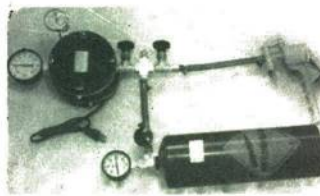
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Fujichrome RD100, fine grain slide	24	\$12.95
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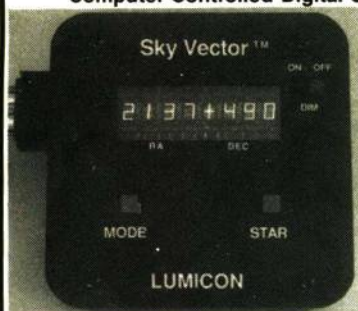
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COMA CORRECTOR



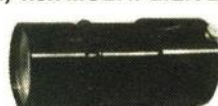
Coma 1 inch off-axis 17 1/2" f/4.5

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This computer-designed LUMICON 2" lens reduces coma and flattens the field for both viewing and photography. It threads into LUMICON 2" EASY-GUIDERS for effortless installation. This lens is optimized for f/4.5 and reduces aberrations for f/3.5 to f/5 Newtonians. Off-axis images are much smaller, making off-axis guiding far easier and yielding round pinpoint star images in photos. Since star images are sharp over a full 2 1/4" circle, you can use medium format cameras in addition to 35mm cameras. This zero power lens does not change image scale nor shift focus, and all lens surfaces are multi-coated for highest efficiency. Although designed for photography you may also use this lens to improve image quality in wide-field viewing with low power eyepieces.

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1.8x Multiplier Lens

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Yellow	480nm-IR	98%	\$18
Green	490-590nm	60%	\$18
Orange	560nm-IR	98%	\$18
Red	600nm-IR	98%	\$18
H-Alpha Pass	640nm-IR	95%	\$35
Cyan	340-580nm	95%	\$59
Adapter for 1 1/4" eyepieces			\$20



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These adapters allow high magnification photography of the Moon and Planets using eyepiece projection. They may be used without any eyepiece for prime-focus photography. All adapters use standard camera T-rings.
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Visual Astronomers prefer the LUMICON 80mm SUPER-FINDER™, since hundreds of deep-sky objects, including most Messier objects, are visible directly. SUPER-FINDERS also make nice small portable telescopes. 80mm aperture, F=300mm coated achromat. The deluxe SUPER-FINDER uses an 80mm, F=500mm air spaced achromat.
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These adapters convert refractors and Schmidt-Cassegrain telescopes for 2" operation. They allow use of 2" accessories, such as the LUMICON 2" EASY-GUIDER for photography. They also allow use of 2" eyepieces and/or 2" star diagonal for viewing.
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Galaxies at the Confusion Limit

New observations show that galaxies formed earlier in the universe than most theories predicted.

by Jeff Kanipe

Pushing telescopes and sensitive light-gathering detectors to their absolute limits, a team of American and Canadian astronomers has looked deeper into the universe than ever before. What they found are thousands of faint, fuzzy objects strewn across tiny regions of sky, regions that appear virtually empty on the most sensitive photographic plates. The leader of the team, J. Anthony Tyson of AT&T Bell Laboratories in Murray Hill, New Jersey, believes these fuzzy objects are galaxies that formed soon after the Big Bang.

"We are seeing galaxies as they were during their youth, just a couple of billion years after the Big Bang," said Tyson. "The sky is completely covered with these exceedingly luminous [galaxies in the] early stages of star formation." At the depth reached by their optical survey, said Tyson, the universe approaches the "confusion limit," beyond which galaxies no longer appear as distinct entities.

The road to this intriguing discovery began in 1983 when Tyson and Patrick Sweitzer, now at the Space Telescope Science Institute, set out to develop deep-sky imaging and photometric techniques to the theoretical limits of sensitivity and accuracy. This involved long exposures and extensive image processing.

The team selected twelve regions of the sky, each with an area of 4 by 6 arcminutes, well away from the dusty plane of the Milky Way and free of bright stars and galaxies. These were "blank" fields — essentially clear, uncluttered views of the deep universe. To gather the light they used the 4-meter telescope at Cerro Tololo Interamerican Observatory in Chile; a charge-coupled device was used to record the images.

The field of view in each of the twelve regions of sky was about 3 by 5 arcminutes, an area only 1/200 that of the Full Moon. These regions are



A FEW STARS AND GALAXIES appear in this 45-minute exposure of a typical region near the south galactic pole taken with the 4-meter telescope at Cerro Tololo, Chile. The faintest magnitude is about 23.

fifty to one hundred times smaller than those used by astronomers in surveys of the nearby universe. Nonetheless, over a thousand fuzzy objects were seen in each field. The total number of objects in all twelve fields was about 25,000. If there are as many of these objects in similar size fields throughout the rest of the sky, there should be about 20 billion objects in all.

"There are so many of them," said Tyson, "that no matter where you aim your telescope, you should see thousands."

The conclusion that these objects are galaxies was not made easily. First, Tyson and Sweitzer had to be certain that the objects truly existed and were not anomalies of their imaging system. After processing and "cleaning up" the images — removing spurious data from irregularities in the CCD chip, bad pixels, and random cosmic-ray

events — they re-examined the fields with the 3.6-meter Canada-France-Hawaii Telescope at Mauna Kea. The same objects were found.

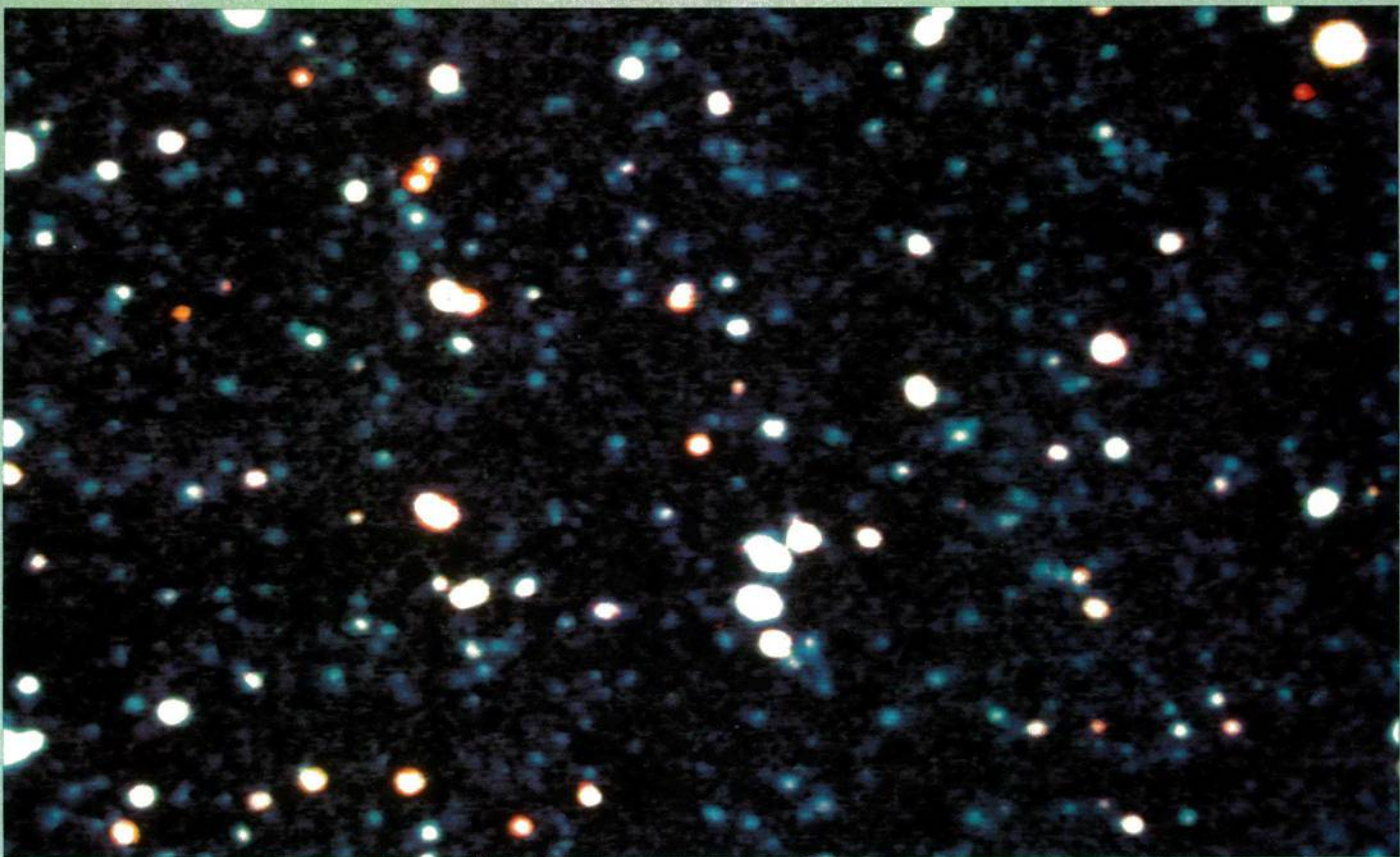
Next Tyson asked himself whether these objects were nearby. Might they be an abundant population of star-poor, low-surface-brightness dwarf galaxies without cores or interstellar clouds? The lower limit on the size of dwarfs in the Local Group of galaxies is about 1,000 light-years in diameter — one hundred times smaller than our Galaxy. Because they are so small and so faint, dwarf galaxies can only be seen relatively nearby; hence their true abundance in the universe is unknown.

This explanation was quashed when Tyson took spectra of the brightest objects. "The spectroscopy we've done has ruled out the hypothesis that these [objects] are nearby, very sub-luminous galaxies," said Tyson. "They're extremely blue and have fairly high redshifts." The fainter objects "have the same color and the same spectral shape as the brighter ones" and are probably even more distant. The redshifts of the brighter objects range from about 0.7 to 3, which corresponds to a distance bracket of between 7 billion and 11.4 billion light-years. In other words, these objects lie in quasar country.

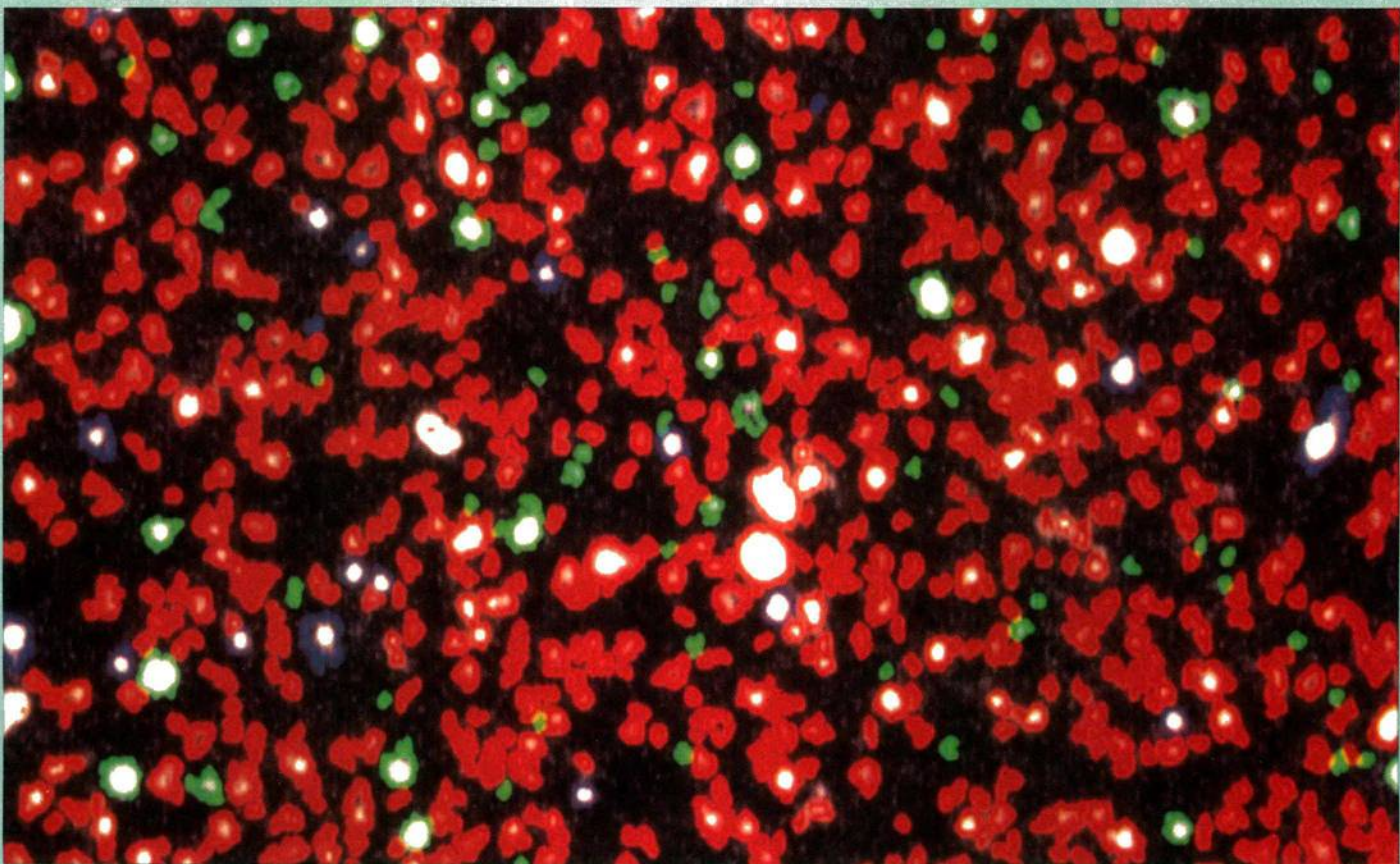
The objects are not point sources, which is how high-redshift quasars appear on photographic plates. "We can resolve these objects," said Tyson. "They are a few arcseconds across, but they are definitely nucleated objects; they are not completely diffuse."

In Tyson's mind, that leaves only one explanation: these objects are galaxies that formed a few billion years after the Big Bang.

If indeed thousands of distant young galaxies cover every 15 square arcminutes of sky, what can that tell us



GALAXIES EMERGE in a true-color CCD image of one of the survey fields. Most of the 1,500 objects shown are galaxies. A total of six hours of CCD exposure time was used — two hours each in red, blue, and infrared wavelengths.



GALAXIES DAPPLE THE FIELD after the original CCD image above is processed and color-coded. Galaxies are red, galaxies with stellar cores are blue, and stars are green. Many galaxy images appear to overlap.

Galaxies as Far as the CCD Can See

Confusion Limit

Field of View

Local Universe

Our Galaxy

At great distances and at fainter and fainter magnitudes, the number of galaxies increases until, as seen from our Galaxy, they nearly overlap. The universe at this depth approaches the "confusion limit," the limiting distance beyond which galaxies no longer appear as distinct objects.

about galaxy formation? For one thing, Tyson said, the distribution of these galaxies strongly suggests that the galaxies have been evolving at a gradual rate since the early universe. This contradicts the popular "starburst" models that require young galaxies to form all of their stars at the same time.

If the stars in galaxies evolved at the same time, then a pronounced peak should be seen in a plot of the number of galaxies at a given redshift (or age). That bump would correspond to the star-forming epoch that began simultaneously everywhere in the universe. But Tyson saw no evidence of such switched-on star formation.

"What we in fact see," Tyson explained, "is evidence for gradual star formation in galaxies."

Instead of galaxies appearing suddenly in the universe, as some astronomers believe, Tyson's data confirms that some of the earliest galaxies formed disks of stars around a redshift of 4, which corresponds to an epoch about 1 billion years after the Big Bang. From there "mild and continuous" evolution of galaxies occurred over the next 5 billion to 6 billion years.

"I think these observations are beginning to constrain the theories," said Tyson. "We may in fact come up with a major conflict that will give rise to a completely new paradigm."

Tyson's data conflict mainly with the cold dark matter model, which is the most successful galaxy-formation model yet proposed. In this scenario the post-Big Bang universe is filled with dark matter composed of massive, slow-moving particles around which the first galaxies form. But this theory requires that the majority of star formation in young galaxies occur at redshifts less than 1. In other words, galaxies with ongoing star formation shouldn't be plentiful at redshifts greater than 1. Yet Tyson seems to have found thousands, perhaps billions, of such galaxies.

The crux of the matter is that there is only a certain amount of time to form galaxies and a certain amount of time to form stars. In a universe dominated by cold dark matter, said Tyson, it takes 1 billion or 2 billion years for galaxies to condense from the primordial gas of the Big Bang, and then another billion years for stars to form in those galaxies. That's too much time, according to Tyson's observations, which require galaxies to form stars at about a redshift of 4 or greater. This epoch occurs only 1 billion years after the Big Bang. With some stretching, Tyson's observations can fit the cold dark matter model, but just barely.

"Our data seems to say that current models of a completely cold dark matter universe are difficult, not ruled out, but simply difficult," said Tyson.

Astronomers following Tyson's work are excited, but they also want more proof. "I think it's fascinating," said Lennox L. Cowie, assistant director of the Institute for Astronomy at the University of Hawaii and a specialist in galaxy formation. "But the question still remaining is, What are those objects?"

Cowie cited a recent redshift survey conducted by astronomers at the Anglo-Australian Observatory, in which a population of blue galaxies was detected at relatively low redshifts (although the galaxies in that survey were not as faint as the galaxies in Tyson's deep CCD survey).

"The difficulty is that it's very hard to distinguish between a galaxy in the process of forming and one that has just rejuvenated itself by doing a lot of star formation," Cowie said. "They both look very similar and there really aren't a lot of diagnostics to tell the difference between the two."

"What's needed is to establish their redshifts," Cowie said, referring to Tyson's galaxies. "It's tough because these objects are so faint. But it can be done by spending several nights working with a large telescope."

Tyson in fact plans further surveys that will examine many more regions of sky and wider fields of view. Essentially his research will explore two main avenues: the shapes of these farflung galaxies and the search for intervening gravity lenses.

"We want to investigate the shapes and detail surface brightness distributions of these very faint blue galaxies," Tyson said. Using the Canada-France-Hawaii Telescope atop Mauna Kea, Tyson's team has been getting a factor of two better angular resolution than at other observing sights.

On a separate tack Tyson wants to use the backdrop of these billions of galaxies as a tool to locate gravity lenses. Any massive foreground objects — such as unseen galaxies — would distort the more-distant background galaxies. Tyson said that systematic distortions of the background galaxy images can be located with an automated detector.

As faint and inscrutable as these distant galaxies seem, they may yet tell astronomers quite a lot about galaxy formation in the early universe and perhaps even something about the landscape of the universe out to this confusion limit. Undoubtedly such research will serve as the catalyst to greater understanding. □

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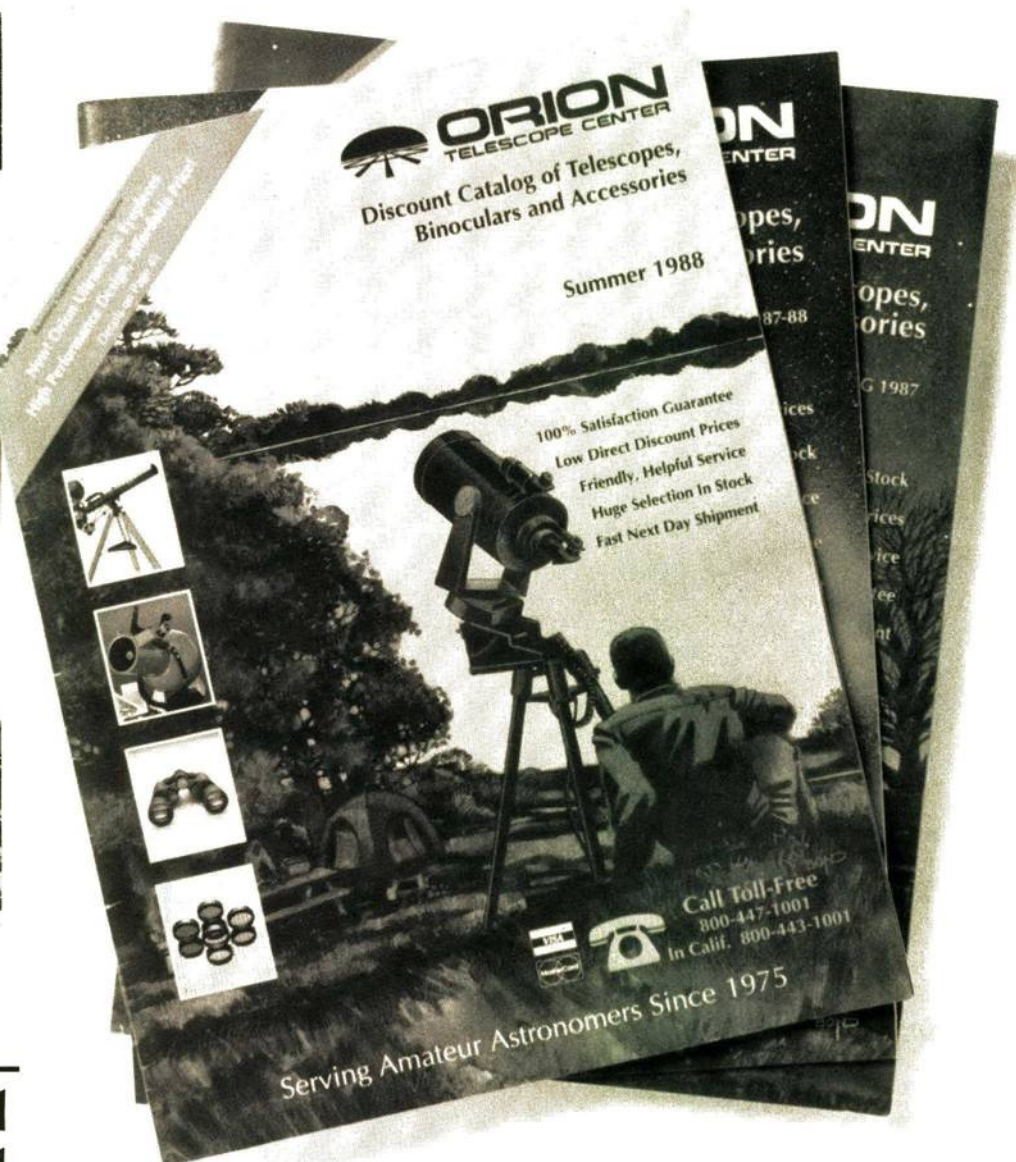


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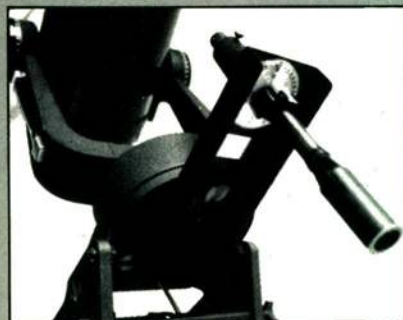
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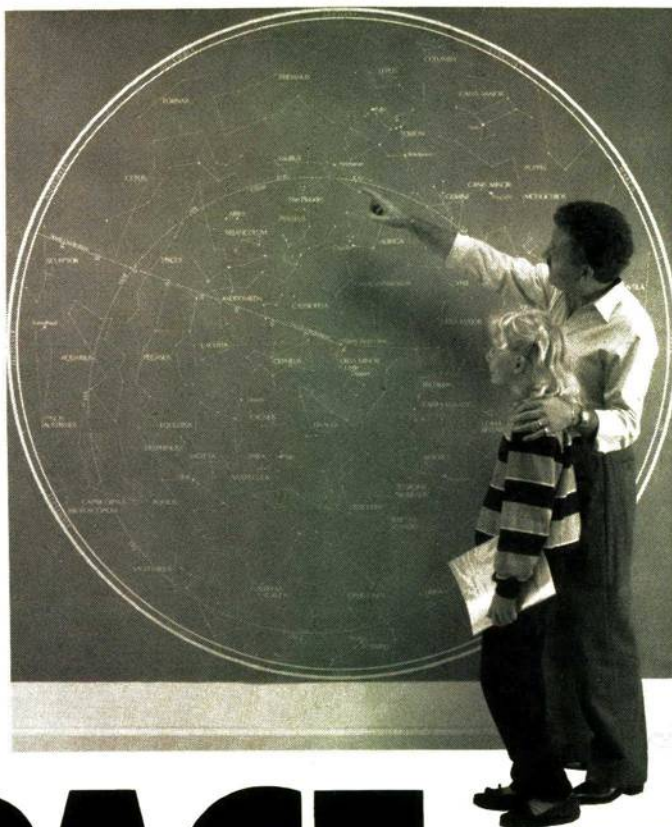
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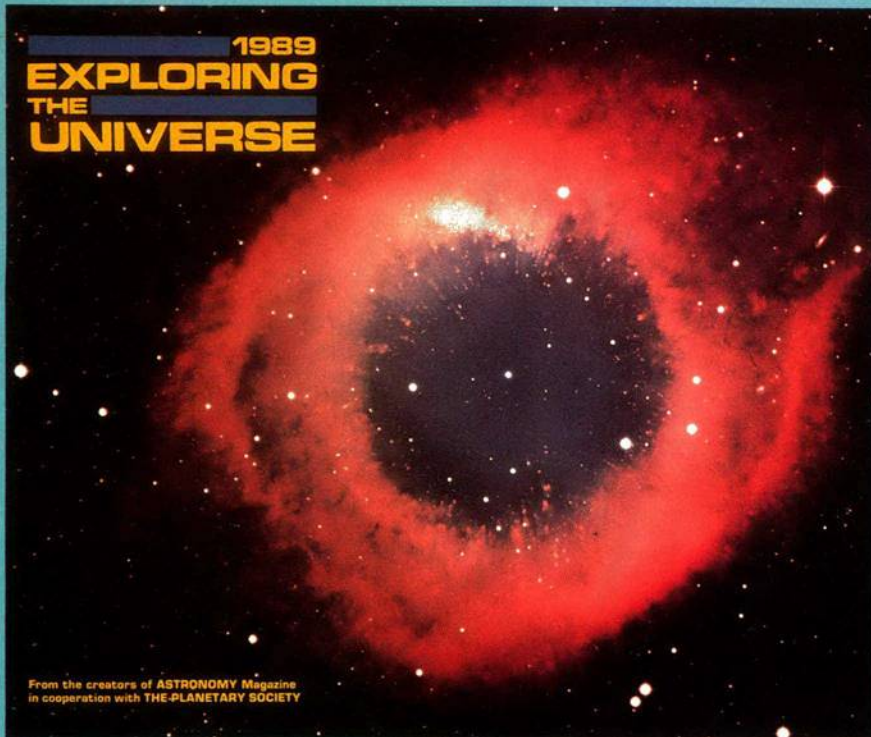
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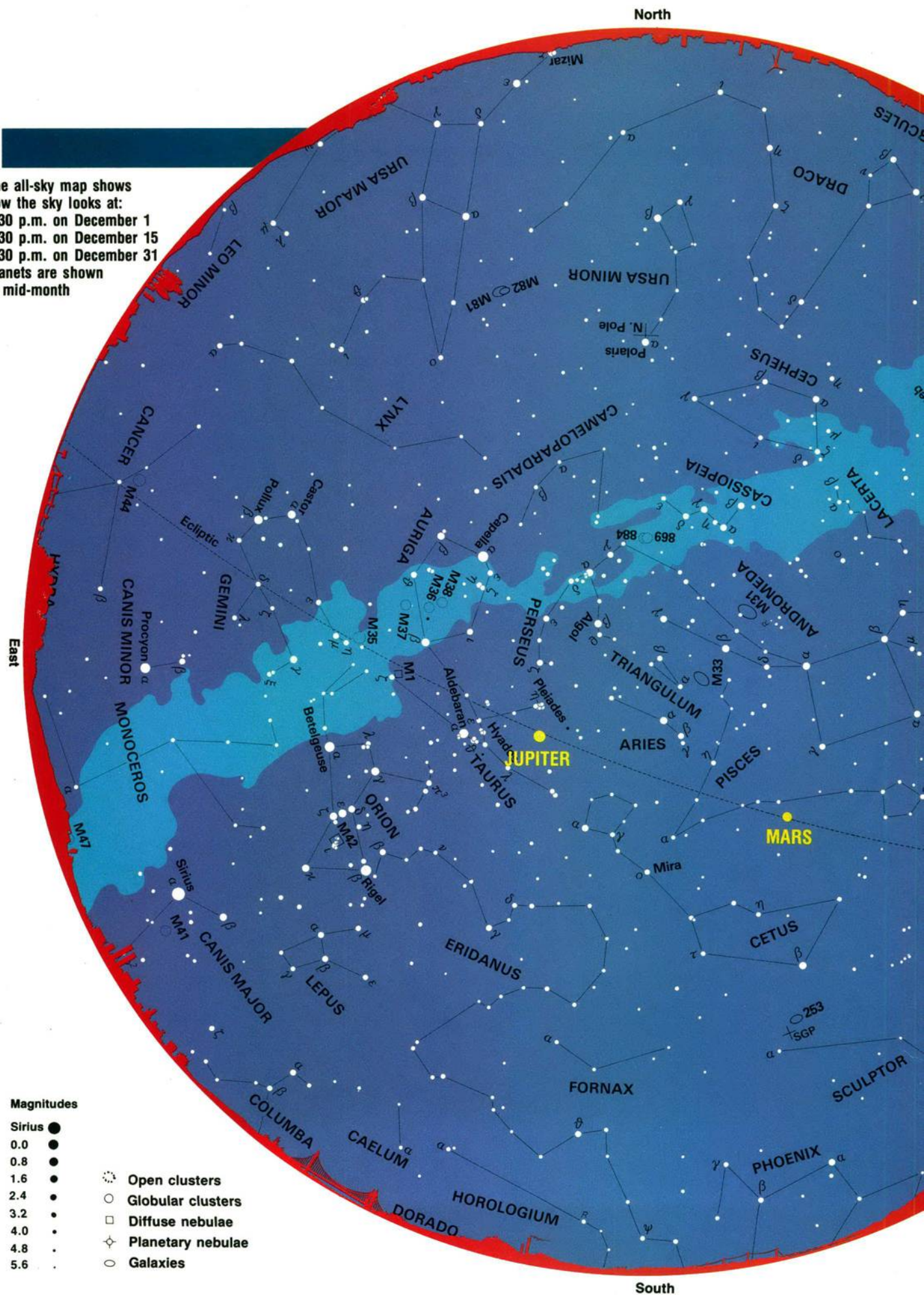
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The all-sky map shows
how the sky looks at:
9:30 p.m. on December 1
8:30 p.m. on December 15
7:30 p.m. on December 31
Planets are shown
at mid-month



Sky Almanac

DECEMBER 1988

GEMINIDS PEAK IN DECEMBER

The Geminids, one of the strongest and most reliable meteor showers of the year, peaks the night of December 12/13. At its peak the shower generally produces fifty to sixty meteors an hour from a dark-sky location; fewer are visible a day or two before and after.

JUPITER DOMINATES EVENING SKIES

Rising in the east as darkness falls, the giant planet Jupiter is the most prominent point of light in the evening sky. Jupiter is now slightly fainter and smaller than last month when it was at opposition, but it is still a "must see" object for naked-eye observers and those with a telescope.

MIRA AT ITS BRIGHTEST

Reaching the culmination of an 11-month cycle, the variable star Mira should peak in brightness in the first half of December. At maximum brightness Mira is an easy naked-eye object, but some optical aid will be necessary to follow the star as it fades over the next several months.

DOUBLE STAR OCCULTED BY MOON

A waxing gibbous Moon occults the two component stars of Epsilon Arietis in rapid succession on the evening of December 19.

Dates and Times

- | | |
|--|---|
| 1 Last Quarter Moon,
1:49 a.m. EST
Mercury in superior
conjunction | 21 Winter solstice,
10:28 a.m. EST |
| 2 Moon at apogee
(251,255 miles from
Earth) | 22 Uranus in conjunction
with Sun |
| 9 New Moon, 12:36 a.m.
EST | 23 Full Moon, 12:29 a.m.
EST |
| 13 Geminid meteor shower
peaks in morning | 26 Saturn in conjunction
with Sun |
| 15 Moon at perigee
(230,128 miles from
Earth) | 27 The Moon passes 0.2°
north of Regulus,
3 p.m. EST |
| 16 First Quarter Moon,
12:40 a.m. EST | 29 Moon at apogee
(251,267 miles
from Earth) |
| 17 The Moon passes 3°
north of Mars,
11 a.m. EST | 30 Last Quarter Moon,
11:57 p.m. EST |
| | 31 Neptune in conjunction
with Sun |

WATCHING THE GEMINID METEOR SHOWER

Conditions are excellent this year for watching what many people consider the best meteor shower of the year. The Geminid meteor shower peaks on the night of December 12/13 and should be good the night before and after. The waxing crescent Moon sets in mid-evening on those dates and the radiant point of the shower, located in the constellation Gemini, is highest in the sky shortly after midnight. At the shower's peak you can expect to see about one meteor per minute under a dark sky.

The title of "best meteor shower" used to be held by the Perseid meteor shower in August. But the Perseids have grown slightly weaker in recent years and the Geminids somewhat stronger.

About two thirds of Geminid meteors appear white, in contrast to the Perseids, which come in various brightnesses and in as many delicate colors as the stars themselves. In addition, the Geminid meteor shower is one of the few showers that puts on a good show in the hours before midnight.

To watch this year's Geminid shower, make sure to dress warmly (or use a sleeping bag to conserve your body's heat) and bring a blanket or lawn chair to lie down on. You should view the shower from a location away from city lights after the Moon has set.

Although they are sometimes called "shooting stars," meteors in showers actually originate in comets. Comets litter their orbits with bits of rocky debris released when ices in the comet's nucleus evaporate in the Sun's heat. When Earth encounters the orbit of a comet (and we encounter dozens every year), this debris plunges through our atmosphere and vaporizes, causing a meteor shower.

JUPITER BRIGHT IN THE EVENING SKY

Jupiter, the king of the planets, dominates the December heavens. It is ascending in the east when darkness falls each evening and doesn't set until shortly before dawn.

Jupiter is now only one month past opposition, when Earth passed between the planet and the Sun. As a result, it remains very bright in our sky, shining at magnitude -2.8 . Binoculars reveal Jupiter as something other than a star. And if you hold the binoculars steadily enough, you may glimpse some starry points near the planet — Jupiter's moons. These

moons, by the way, are bright enough to be seen with the naked eye. However, they are difficult to see, even with binoculars, in Jupiter's glare.

The planet appears in the constellation Taurus in the general direction of two prominent star clusters, the dipper-shaped Pleiades and the V-shaped Hyades. These clusters tend to capture one's eye anyway; their proximity to Jupiter now makes them irresistible.

SUN AT ANNUAL LOW

The winter solstice arrives on December 21 at 10:28 a.m. EST. At this instant the center of the Sun reaches its southernmost point on the imaginary celestial sphere surrounding Earth, and winter officially begins in the Northern Hemisphere.

The Sun now makes a low arc

A GEMINID FIREBALL blazes across the skies of northeastern Kansas in December 1979. Photo by Rick Schmidt.



across the sky each day. As a result, there are fewer hours of daylight now than in summer. The longer nights provide more dark hours for stargazing, which you can enjoy if you find ways to combat the cold!

A good way to visualize the Sun's low path across the sky is by noting the Sun's height at noon. Use a straight stick, or gnomon, planted securely in the ground. (The same trick can be done indoors if you have a south-facing window and a stationary object to cast a shadow.) Mark the position of the shadow on the ground each midday, when the shadow is shortest and falls due north of the stick. The noon shadow at the winter solstice will be longer than any other during the year, a fact you can substantiate during the month of December. If you're more ambitious, extend your observations over a full year and observe the entire range of the shadow's length. Some of the earliest astronomical observations probably involved no more than a stick in the ground, to measure the height of the Sun.

The pattern of sunrises and sunsets is also interesting to watch in the weeks surrounding the solstice. The fewest hours of daylight occur on the solstice, but that is not the day of the latest sunrise or the earliest sunset. The day of earliest sunset occurs roughly two weeks before the solstice at mid-northern latitudes, though it varies depending on latitude. Although the Sun sets earlier on this date than on the solstice, it rises earlier too, which allows more total minutes of daylight. The latest sunrise, by the way, comes in early January.

Finally, watch for this month's Full Moon on the night of December 22/23. Because the Moon appears full when it is opposite the Sun in our sky and because the Sun is now lower than at any other time of the year, this month's Full Moon rides particularly high in the sky.

DECEMBER'S PLANETS

Saturn is nearly lost in the evening twilight as the month begins. It is low in the southwestern sky and much diminished because we have to peer at it through a great deal of Earth's atmosphere. Plan on viewing Saturn early this month — it disappears after the first week of December.

Since we passed between this planet and the Sun last June, Earth has pulled far ahead of Saturn in the race of the planets. Because our orbit is smaller, we move much faster than Saturn: an average speed of eighteen miles per second in contrast to Saturn's six miles per second.

Thus, every year we watch Saturn grow bright in our sky and then fade again as it appears to back away into the Sun's glare. On December 26 the planet is most directly behind the Sun as seen from Earth. It will return to the predawn sky in early 1989.

High in the southeast as darkness falls, Mars appears respectably bright and distinctively orange against the stellar background of the constellation Pisces.

Like Saturn, Mars always appears brightest in our sky when it is closest to Earth. This year we sped between Mars and the Sun in September, and the planet's brightness has dropped dramatically since then. In each of the last two months Mars has dimmed by a whole magnitude: it was two-and-a-half times brighter at the beginning of each month than at the end.

This month Mars' plunge in brightness levels off a bit. The planet shines at magnitude -0.8 at the beginning of the month and hits magnitude -0.1 by New Year's Eve. It will continue to fade, albeit at a slower pace, in the coming months.

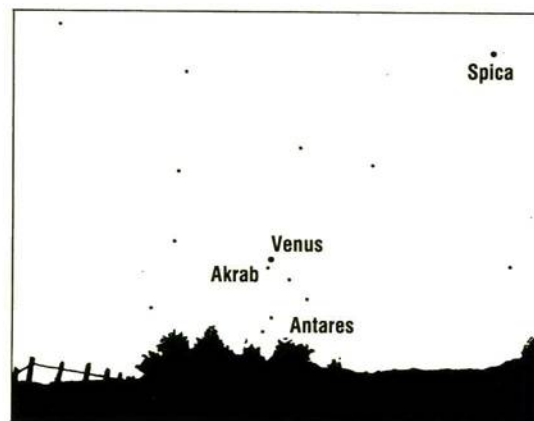
Jupiter is the bright object below Mars in the east when night falls. It is more than two magnitudes brighter than the Red Planet and appears white compared with Mars' ruddy color. By mid-evening Jupiter and Mars are striking, side by side in the southern sky.

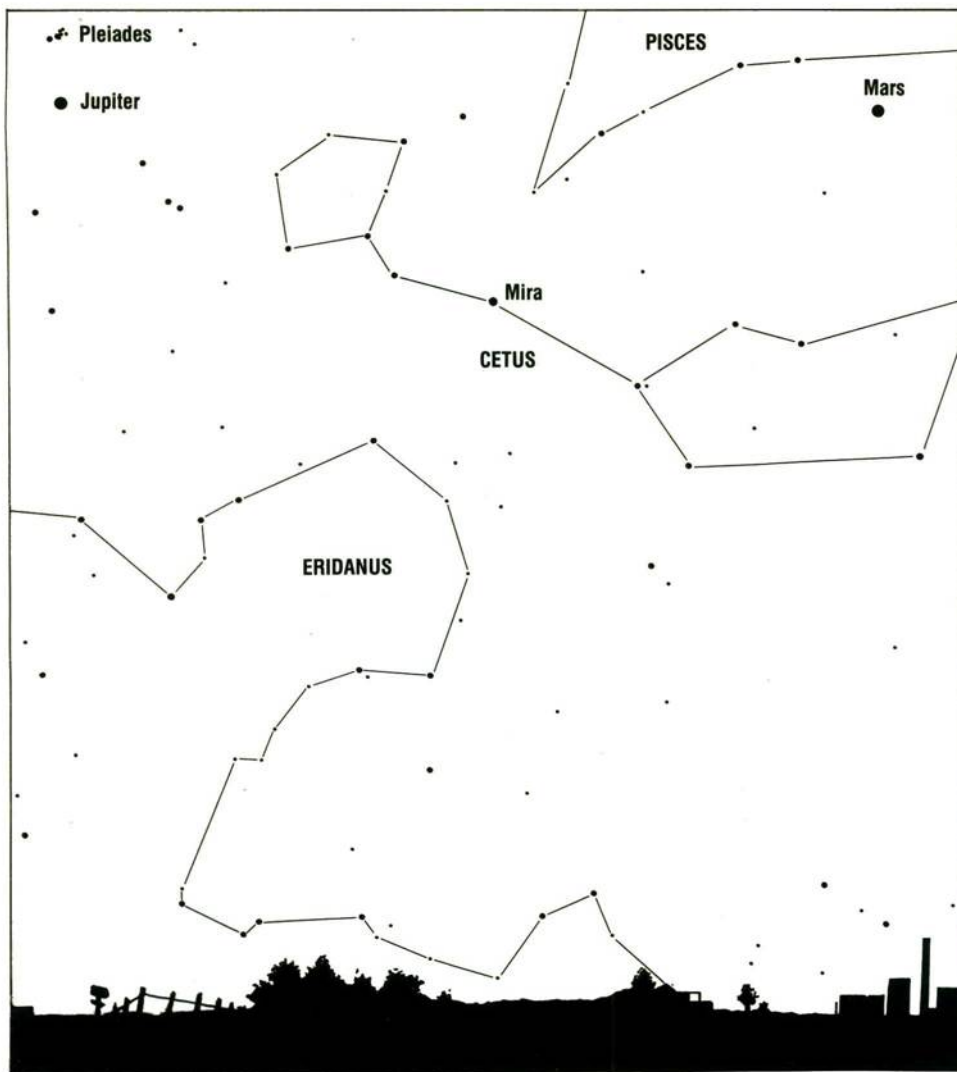
Venus is still a brilliant "morning star" in December. At magnitude -4.0 for most of the month, it outshines everything else in the sky except the Sun and Moon.



A SHADOW AT MIDDAY is longer on the winter solstice than on any other day of the year. You can prove this by pounding a stake in the ground vertically and measuring the length of the stake's shadow each sunny day at noon during December.

VENUS WELCOMES SCORPIUS into the morning sky this month. Look for the bright planet above the star Akrab about an hour before sunrise on December 19.





MIRA THE "WONDERFUL" is an exotic star that dramatically varies in brightness. Mira reaches peak brightness this month and will be visible in the south, below the bright planets Jupiter and Mars, on December evenings.

gaze toward the southern sky. If you look below the planets in the south, you should see a reddish star that forms a triangle with them. I can't tell you precisely how bright this star will appear. That's the fun of it. It's one of the most famous variable stars in the sky, Omicron Ceti, also known as Mira.

Mira means "wonderful" in Latin. The star is a favorite among sky-watchers, despite the fact that it is invisible to the naked eye for most of every year. Mira becomes visible for only about two months of every eleven. Its maximum brightness this year is predicted for early December, when it may be 4th or even 3rd magnitude or possibly brighter.

Mira was first noted in the western world by Dutch astronomer David Fabricius in 1596. He must have been surprised when it faded from view, and he didn't look for its return. In 1603 Johann Bayer included the star in his famous catalog and gave it the designation Omicron (o) in the constellation Cetus the Whale. Soon afterward it grew dim again, but this time its reappearance was observed. The star has been watched for the nearly four hundred years ever since.

What's exciting about Mira is that you never know how bright it will become. It occasionally reaches 2nd magnitude, and in 1779 it grew nearly as bright as another red star, 1st-magnitude Aldebaran in Taurus.

Mira is one of the few stars both large enough and close enough to Earth for astronomers to measure its diameter. During the course of one cycle Mira pulsates about 20 percent in size. At its largest — when it is also coolest and thus at minimum brightness — the giant star is roughly four hundred times the size of our Sun. At those times if Mira replaced the Sun in our solar system, its outer layers would extend well beyond the orbit of Mars. □

The planet appears low in the southeast as dawn approaches. At the beginning of December it rises about two-and-a-half hours before the Sun, and by month's end it rises just as twilight begins. Venus will remain visible (because it's so bright) through the early part of next year. With binoculars you should be able to follow the planet until mid-February.

From its location low in the sky, Venus is on hand to greet Scorpius as this constellation emerges from the Sun's glare before dawn. Venus slides just north of the star Akrab (Beta [β] Scorpii) in the "crown of the scorpion" on the mornings of December 19 and 20. It passes 6° north of Antares on the morning of December 24.

Mercury is behind the Sun, at superior conjunction, on December 1. By the end of the month the speediest planet may be visible low in the southwestern sky during evening twilight. It will climb higher in that part of the sky and be easier to see in January.

DECEMBER'S STARRY SKY

On these cold December evenings the bright planets Jupiter and Mars are sure to draw your

OBSERVING MIRA AT MAXIMUM BRIGHTNESS

The most famous of all variable stars — and the first one discovered — should attain peak brightness this month. Omicron (o) Ceti, better known as Mira, should reach 3rd or 4th magnitude around December 6.

But one interesting aspect of Mira's variability is that it cannot be predicted exactly. Rather, its period, which averages about 330 days, ranges from a bit over 300 days to nearly 355 days. Also, its maximum brightness generally ranges from magnitude 2.5 to 5, while its minimum brightness normally ranges from 8.5 to 9.6. To confound astronomers even more, in 1779 Mira reached a magnitude of nearly 1! So keep in mind that the predictions of Mira's brightness and period are just that — predictions.

You can get an accurate measure of Mira's magnitude by comparing Mira's brightness with the brightnesses of nearby stars of known magnitude. First, use the light curve on page 70 to get a rough idea of Mira's magnitude on the night of your observation. Then choose a group of comparison stars with magnitudes ranging about 1 or 1.5 magnitudes above and below Mira's predicted magnitude from the chart at right. Finally, compare Mira's brightness with the dimmest star you chose, then with the next dimmest, and so on, until you find two stars with magnitudes that bracket that of Mira.

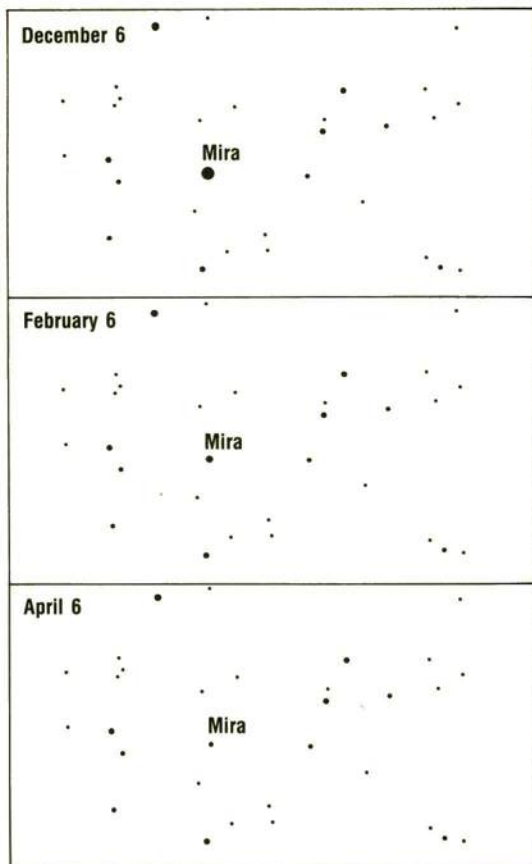
Suppose you observe Mira's brightness to be exactly halfway between that of a 3.5- and a 3.9-magnitude star. You would then estimate Mira's magnitude as 3.7. If, however, Mira seemed closer in brightness to the 3.5-magnitude star, you would estimate the magnitude as 3.6.

Even at its faintest, Mira is bright enough to be seen with a 60mm refractor or a pair of 7x50 binoculars. Thus, you don't need a large-aperture telescope to observe this "wonderful" star — almost any optical aid will do.

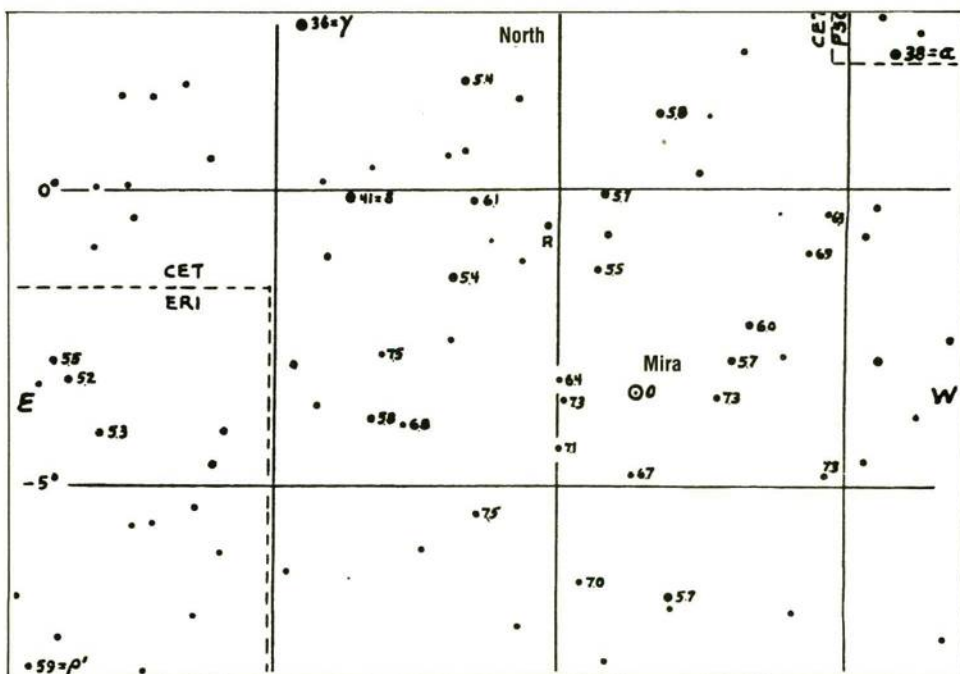
Here are a few hints to help you with your observations of Mira's brightness changes. First, unless you plan to make photographic or photometric estimates of Mira's brightness, you must try to put yourself into a very dispassionate mood before observing. This helps counteract the human tendency to see things as they should be and not as they really are. For this reason you should not make a light curve from your observations until after Mira's brightness fades to a minimum. By plotting your estimates, you may be biasing your observations to make them fit the curve! Also, don't compare your observations with those of a friend, because you might bias his or her estimate and vice versa.

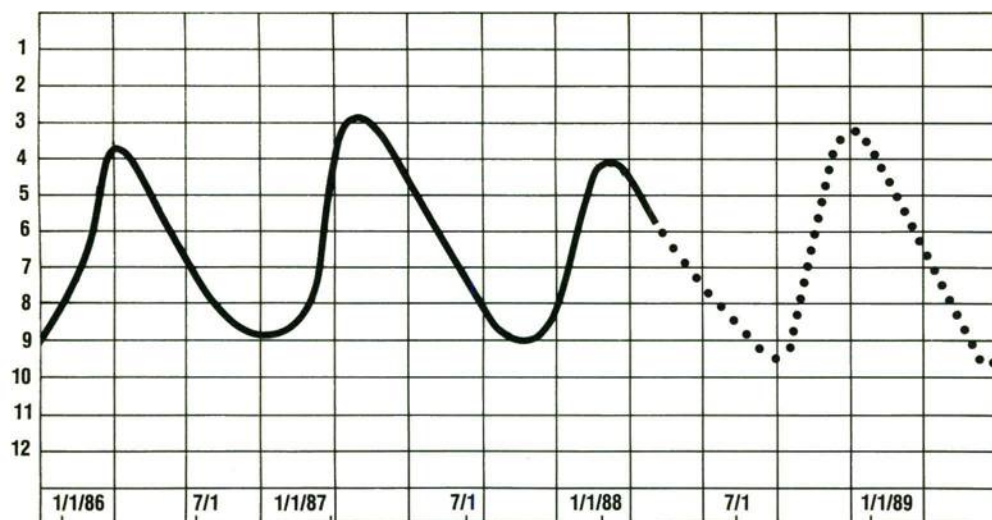
Why does Mira vary in brightness? Astronomers believe Mira — a red-giant star roughly four hundred times the diameter of the Sun — has exhausted all the hydrogen and helium in its core, so fusion in the core is no longer possible. However, pressures in the shells just outside the core are high enough for helium to fuse into heavier elements, so Mira still produces enough energy to counteract the pull of its own gravity. The catch is that this type of fusion is not stable, so Mira pulsates a bit in size and varies a lot in total energy output, by about 2.5 times.

But a change in energy output of 2.5 times corresponds to just one magnitude. How come we see Mira change in brightness by



OBSERVE MIRA FADE over the next few months (above) with the help of binoculars or a small telescope. Use the chart (below) to compare Mira's magnitude with those of nearby stars.





MIRA'S BRIGHTNESS VARIES by about six magnitudes over a period of roughly 330 days. However, as this record of the past several years shows, both the period and magnitude range are far from constant.

JUPITER'S MOON CALLISTO does not always lie in a line with the other Jovian satellites. Four times this month Callisto lies north or south of Jupiter's disk.

December 1
4 a.m. EST, 1 a.m. PST



December 9
10 p.m. EST, 7 p.m. PST



December 17
10 p.m. EST, 7 p.m. PST



December 26
4 a.m. EST, 1 a.m. PST



about six magnitudes? Because Mira is a very cool star: it averages about 1900 kelvins when at minimum and 2500 kelvins when at maximum. When Mira's surface temperature is at the lower value, most of the star's energy is emitted in the infrared region of the spectrum, while at the higher temperature a much larger percentage of the energy is emitted in the visible region. It's our inability to see Mira's brightness in the infrared that causes the huge change in the star's apparent brightness.

JUPITER'S MOONS ON DISPLAY

Having reached opposition less than ten days before the beginning of December, Jupiter is now fading slowly (from magnitude -2.9 to -2.7) and shrinking slightly in the eyepiece (from $48.6''$ across to $46.2''$). Still, Jupiter remains bright and large in the evening sky and shows more detail at the telescope than any other planet.

When you look at Jupiter in the eyepiece, the first thing you will most likely notice is the four Galilean satellites. The Jupiter's Moons chart on page 72 can help you identify the major satellites by their positions relative to Jupiter and one another.

Most people expect the Galilean moons to be arrayed in a straight line, and they normally are. However, this year the equatorial plane of Jupiter, which is also the orbital plane of the satellites, is tilted the maximum amount relative to Earth. In December this tilt is about 3.6° , so the satellites do not always appear in a line. The effect is most noticeable with Callisto, the outermost Galilean satellite, and best seen when that moon is either north or south of Jupiter's disk. Use the charts at left to find when the events take place this month.

The Galilean satellites may be the only aspect of Jupiter's telescopic appearance that comes in clearly. Despite Jupiter's large size, poor seeing could limit the clarity of Jovian cloud features. However, if you try viewing Jupiter shortly after sunset, you may catch a window of calm in the normally poor winter seeing.

The reason for this sunset calm has to do with the way the atmosphere's temperature changes at that time. During the day the atmosphere is warmest near the surface and cools as you reach higher and higher altitudes. At night the surface radiates its heat to the cold sky, so the temperature of the atmosphere is usually cooler near the surface and warms as you go up. (Of course, at some altitude this trend reverses.) The important point to remember is that just after sunset the atmosphere is making a transition from daytime conditions to nighttime conditions. At some point during this transition there is little or no temperature change, which means there is also little or no turbulence and thus great seeing. That's the good news. The bad news is that so many factors affect the weather that this somewhat simple-minded model doesn't always apply. However, this phenomenon occurs often enough that it pays to be ready to do your planetary observing at times when the model does apply.

The next time your family gets together and your Aunt Edna comments on "how wonderful it is that the stars are twinkling so much tonight," remain patient and charitable as you explain to her that looks can be deceiving and that you like it best when the stars don't twinkle!

A FAST OCCULTATION OF A DOUBLE STAR

A waxing gibbous Moon occults the close double star Epsilon (ϵ) Arietis on the evening of December 19. The event is particularly interesting because telescopic observers will be able to see the dark limb of

the Moon occult the two 5th-magnitude component stars in rapid succession. The event is visible north of a line that runs approximately from Cape Cod through central Delaware, central Virginia, Atlanta, and New Orleans, although sunlight interferes for observers on the West Coast. The times of disappearance for the double star are given at right for several cities, as is a representative view of the event.

TELESCOPIC PLANETS

Mercury becomes visible in the evening sky very late this month, but it will be higher above the horizon during the first weeks of next year. If you have a very clear atmosphere and a very low western horizon, you might spot 5.5"-diameter Mercury just after sunset during the last days of the year.

Venus is well placed for observation this month in the predawn sky. At the beginning of December Venus rises about an hour before twilight begins, while at the end of the month it rises at the beginning of twilight. During the month the disk of Venus shrinks from 12.1" to 11.0" across, while Venus' magnitude drops imperceptibly from -4.0 to -3.9. You'll notice little change in Venus' disk during this period, because the planet is nearly on the opposite side of the Sun from us and is approaching full phase.

Mars, the third and final planet you can see well in December, is high in the sky as evening twilight deepens and transits at about 7 p.m. local time. Well past opposition now, Mars fades from magnitude -0.8 to -0.1 during December and is less than 10" across at the end of the month. Despite being only half the size it was at opposition, Mars is well placed in the sky and should give you some nice views.

Saturn, Uranus, and Neptune all reach conjunction with the Sun this month, on the 26th, 22nd, and 31st, respectively, and offer little for telescopic observers. These planets will become visible in the morning sky late in January.

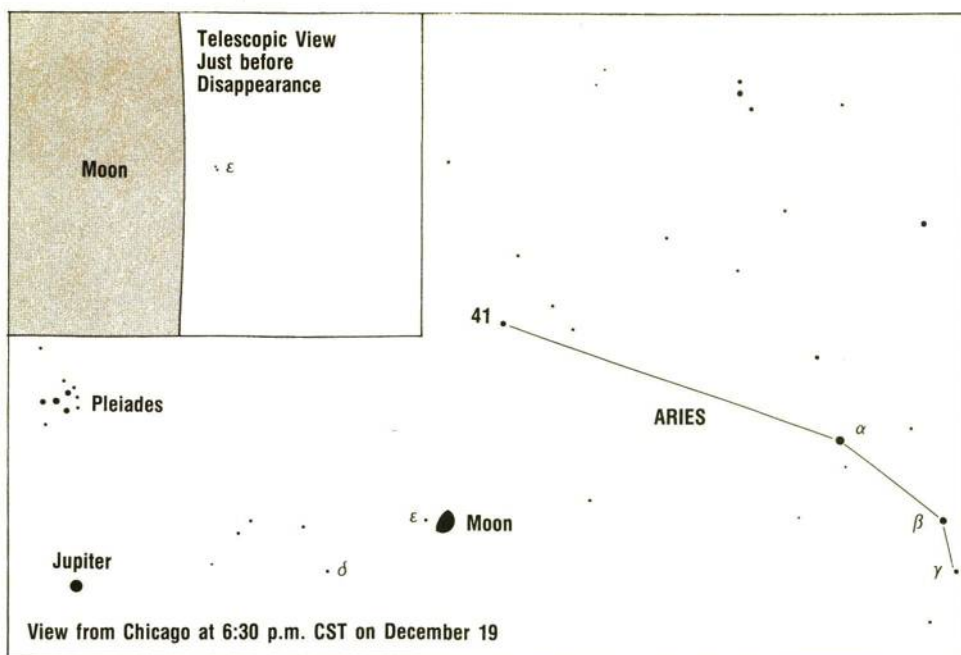
COMETS FOR THE TELESCOPE

Comet Tempel 2 should be visible in 6- to 8-inch telescopes during early December. Fading since it passed perihelion in the middle of September, Tempel 2 is predicted to be 10th magnitude at the beginning of the month.

Thus far, Tempel 2 has been a bit fainter this apparition than predicted in the *International Comet Quarterly* but not as faint as observations made at previous apparitions would have predicted. With the positions given in the table to the right and a good star atlas, such as *Uranometria 2000.0* or *Sky Atlas 2000.0*, you shouldn't have much trouble finding it. Begin looking for Tempel 2 early in the evening when the comet is still reasonably high in the sky.

ASTERIODS IN THE EYEPIECE

No bright asteroids reach opposition this month. However, 1 Ceres and 18 Melpomene remain well placed in the evening sky for observers with 4-inch or larger telescopes. In addition, three bright asteroids that reach opposition early next year are visible in the morning sky in December. We will give more details on 6 Hebe, which reaches opposition in January, and 3 Juno and 7 Iris, which reach opposition in February, in the coming months.



WATCH THE MOON OCCULT the double star Epsilon (ϵ) Arietis on the evening of December 19. The double star (inset) consists of two 5th-magnitude stars separated by 1.2". The table below lists the times of disappearance for selected cities.

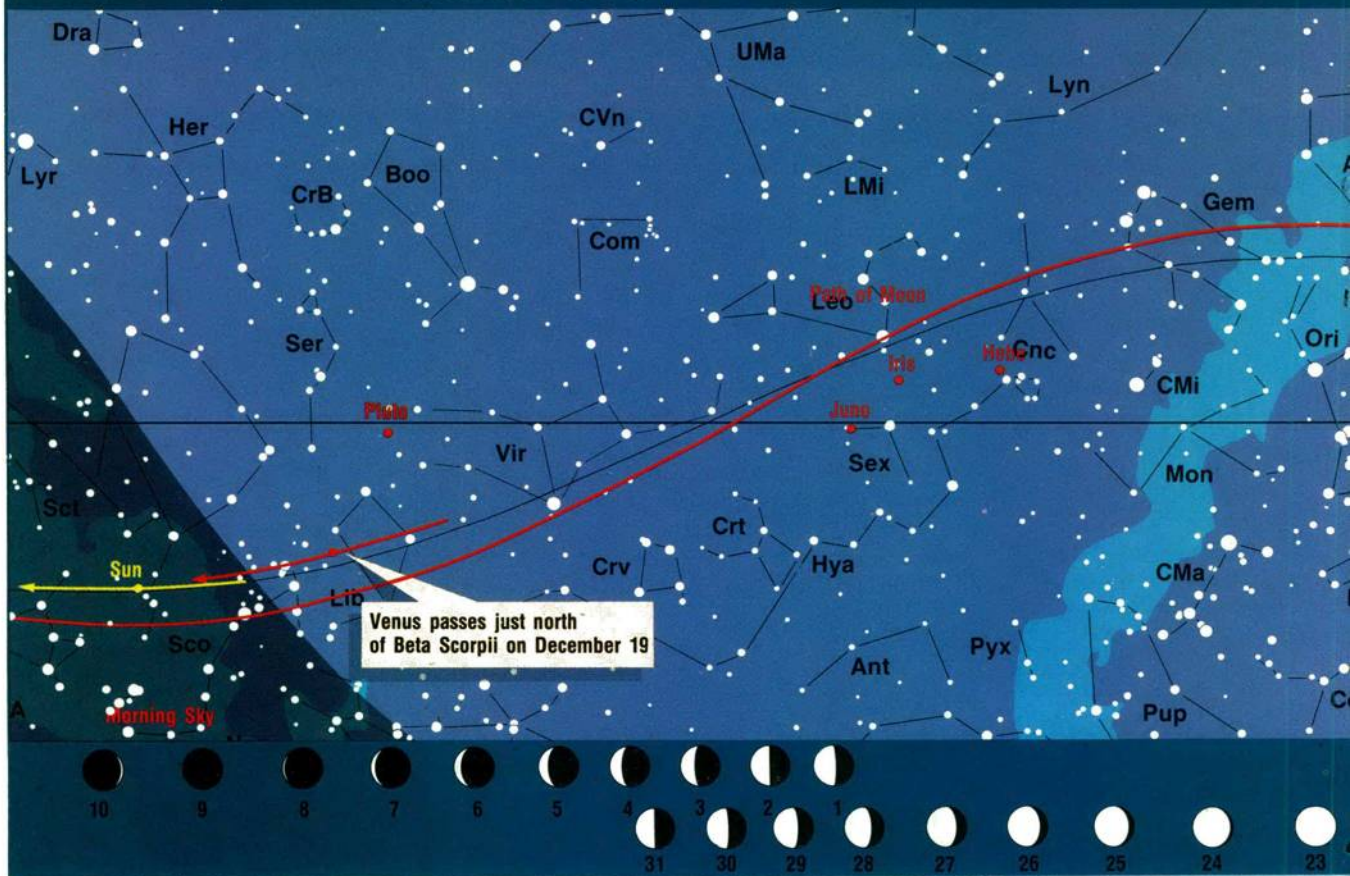
City	Time of Disappearance
Atlanta	7:58 p.m. EST
Toronto	7:59 p.m. EST
Montreal	8:12 p.m. EST
Washington, D.C.	8:14 p.m. EST
Kansas City, MO	6:29 p.m. CST
Chicago	6:42 p.m. CST
Winnipeg	6:42 p.m. CST
Denver	5:20 p.m. MST
Edmonton	5:44 p.m. MST

COMET TEMPEL 2 COORDINATES

Date	R.A. (2000)	Dec.
Dec. 1	22h01.8m	-24°14'
Dec. 6	22h17.8m	-22°56'
Dec. 11	22h31.7m	-21°35'
Dec. 16	22h45.7m	-20°11'
Dec. 21	22h59.7m	-18°46'
Dec. 26	23h12.6m	-17°20'
Dec. 31	23h25.6m	-15°53'

This table gives the position of Comet Tempel 2 at 2 UT on the date shown (9 p.m. EST, 6 p.m. PST the day before).

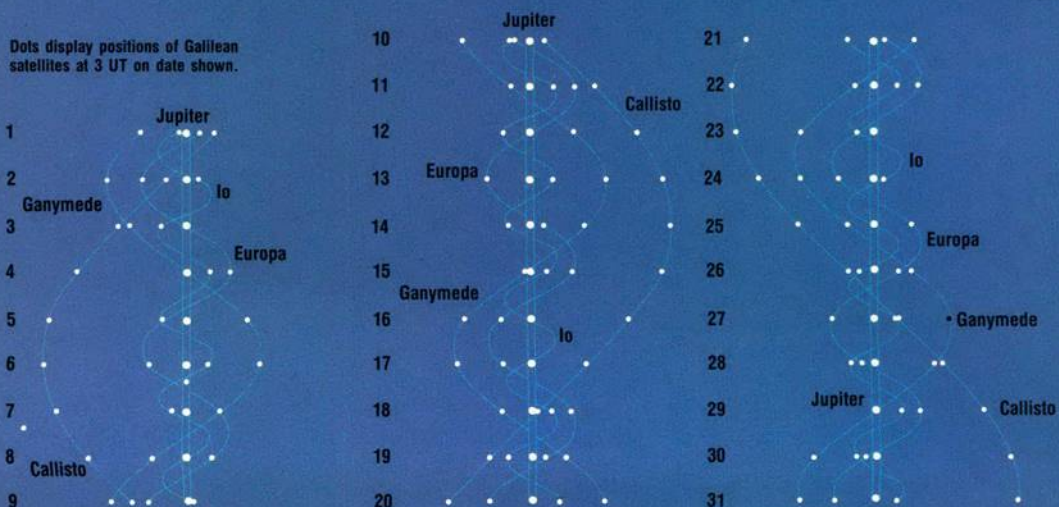
The Solar System December 1988

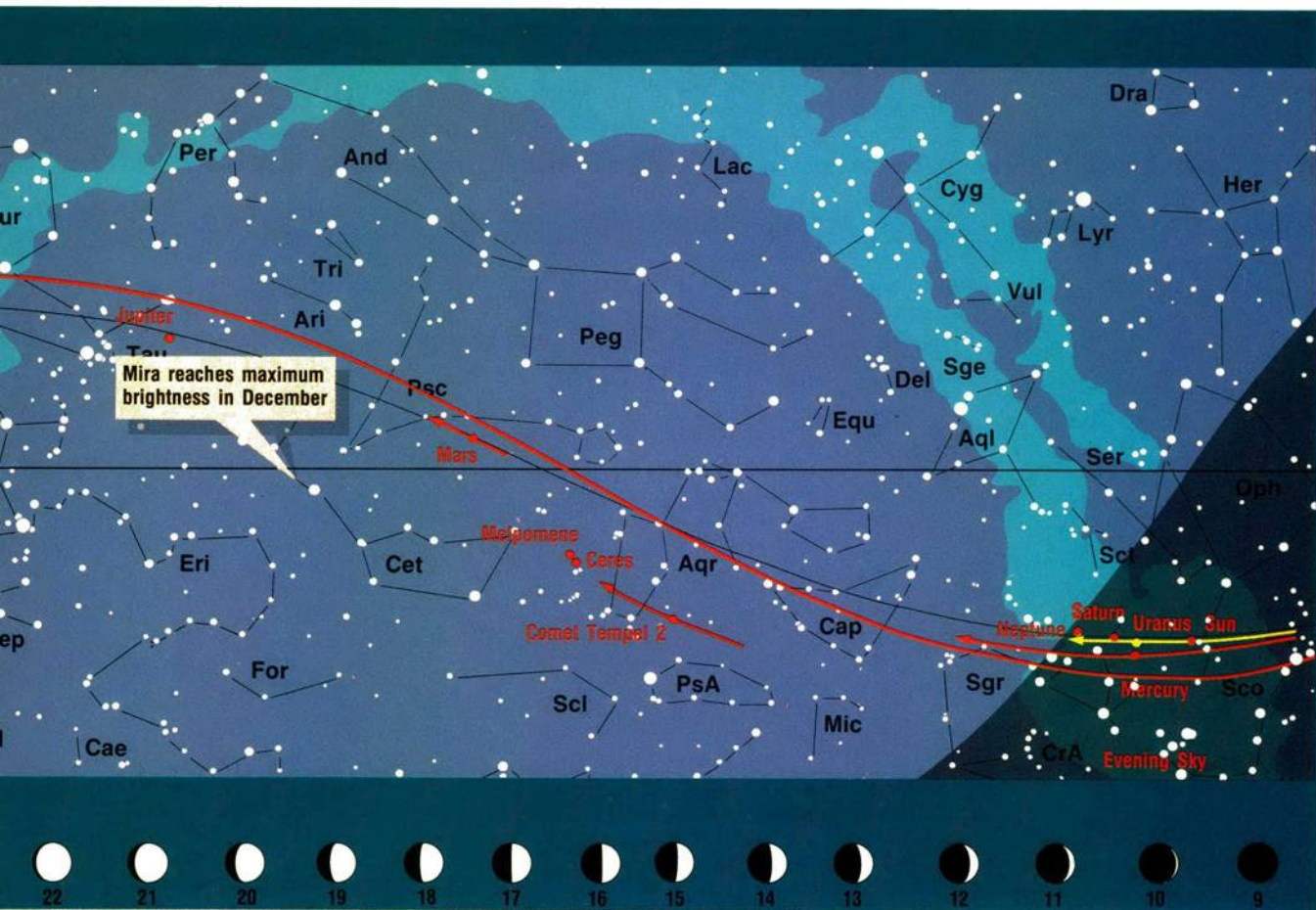


Planet	MERCURY	MERCURY	VENUS	MARS	MARS
Date	Dec. 1	Dec. 31	Dec. 15	Dec. 1	Dec. 31
Magnitude	-1.2	-0.7	-4.0	-0.8	-0.1
Angular Size	4.64"	5.62"	11.5"	13.1"	9.7"
Illumination	100%	84%	90%	90%	88%
Distance (AU) from Earth	1.451	1.196	1.449	0.712	0.967
Distance (AU) from Sun	0.465	0.376	0.721	1.458	1.496
Right Ascension (2000.0)	16h28.5m	19h53.6m	15h39.1m	0h25.0m	1h12.5m
Declination (2000.0)	-22°34'	-22°54'	-18°02'	2°16'	8°15'

Jupiter's Moons

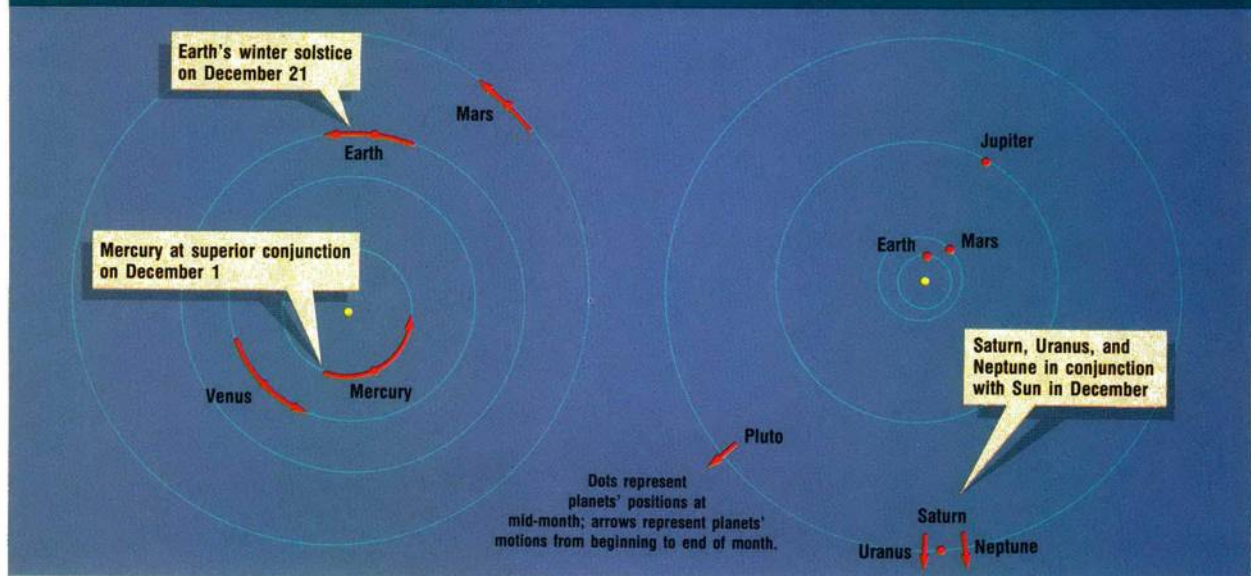
Dots display positions of Galilean satellites at 3 UT on date shown.





JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15
-2.8	+0.5	+5.8	+8.0	+13.8
47.8"	15.0"	3.5"	2.2"	0.1"
100%	100%	100%	100%	100%
4.118	11.010	20.287	31.164	30.387
5.027	10.044	19.312	30.220	29.659
3h45.5m	18h16.2m	18h03.9m	18h40.8m	15h05.2m
18°52'	-22°39'	-23°39'	-22°12'	-1°16'

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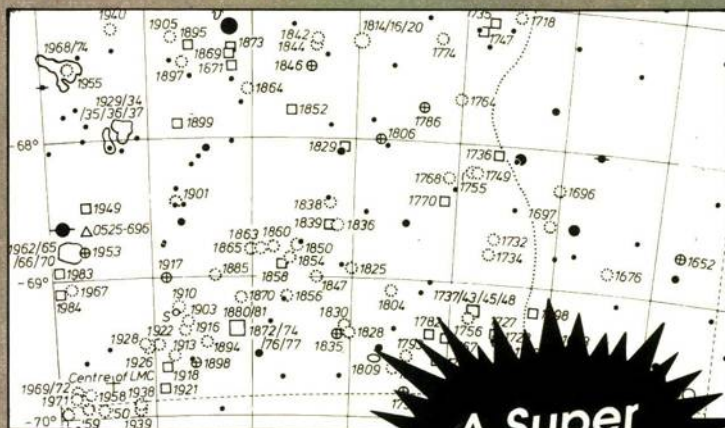
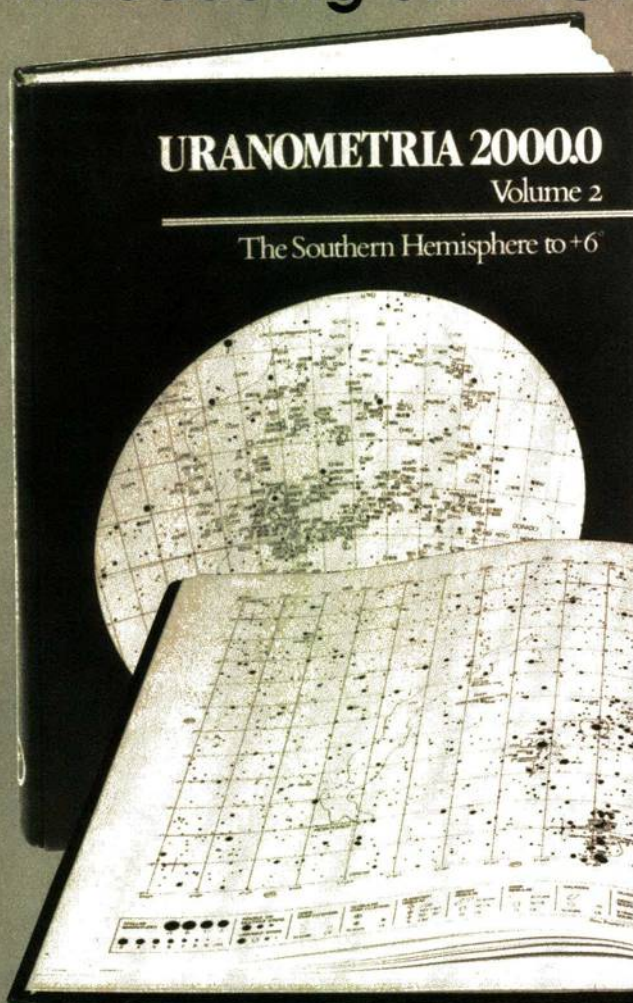
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Mars' Opening Act

Last summer amateurs grabbed every opportunity to observe the Martian surface.

by David J. Eicher

Thousands of amateur astronomers took advantage of the first months of the 1988 apparition of Mars. For many that meant simply getting their first close-up, detailed view of the Martian surface; for others it meant spending countless hours photographing and sketching Mars and analyzing the results.

Mars' spectacular "performance" resulted from two factors: the planet was close to Earth and it was prominently placed in the sky. As Mars approached opposition on September 28, it was just 36 million miles from Earth, near its closest point to the Sun, and visible almost all night from either hemisphere. This gave observers the chance to see detail on Mars including dust clouds, changes in surface features, and a dramatic thawing of the planet's South Polar Cap.

The Association of Lunar and Planetary Observers (ALPO), an organization of amateur and professional planet watchers, operated a worldwide Mars watch. ALPO Mars Recorders Jeff D. Beish and Donald C.

Parker evaluated 13,573 previous Mars observations to predict what might happen this year. They also tabulated events that took place on the Martian surface as the 1988 opposition progressed.

In most cases the Beish-Parker predictions came true, but sometimes they didn't. One of the greatest concerns was a predicted global dust storm that could have covered Mars and prevented observers from seeing detail on the planet's surface. Planetary scientists theorize that when Mars approaches the Sun, rising temperatures on the Red Planet's surface raise winds that stir up dust and keep it suspended in the Martian atmosphere for weeks or months. Mars experts feared a repeat of 1971, when a global dust storm obscured Mars during the last favorable opposition. Planetwide dust storms also occurred in 1956, 1973, and 1977.

Last summer there were no major dust storms. However, several minor dust storms, some creating false alarms, covered small areas on Mars. On May 5, Mars observer Dave Raden sighted a yellow cloud — often a precursor of dust storms — in the Hellas basin. Over the next two days the cloud bloated to the northeast, stretching through Deltoton Sinus and from there northwestward into the Libya basin. At the same time a dull yellow haze covered Sabaeus Sinus and Noachis. The storm rapidly dissipated but

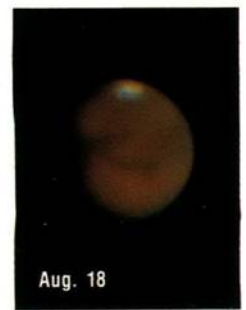
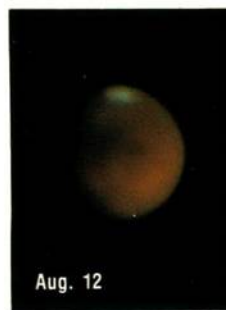
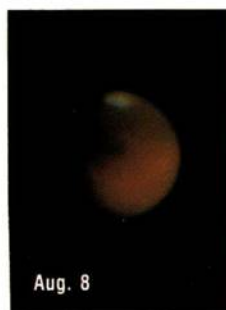
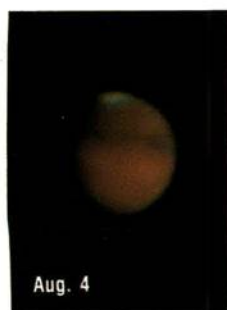
offered a taste of things to come.

In early June a larger dust storm formed in the Hellas basin. On June 3, French observer Gerard Teichert spotted a yellow cloud in Hellas. On June 14 the cloud began expanding rapidly, so that three days later it engulfed several thousand square miles on the planet's surface. The storm obscured part of Mare Tyrrhenum and moved northward into Hesperia. At the same time observers reported several dark streaks crossing Hellas and Eridania. These features had never been observed before, and Beish and Parker feel that "at least one of these streaks, extending from Hesperus to the South Polar Cap, was a shadow cast by the dust cloud onto the Martian surface."

Beish and Parker alerted astronomer Stephen Edberg of the Jet Propulsion Laboratory (JPL), coordinator of "Marswatch '88," a network of Mars observers around the world. Thinking this dust storm might be "the big one," observers in Australia, England, France, Germany, and Japan closely monitored activity on the Martian surface. However, the storm fizzled and the atmosphere cleared by June 21, although JPL astronomers found evidence of higher than normal levels of dust in the Martian atmosphere throughout July.

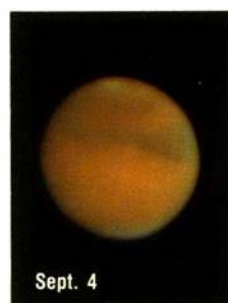
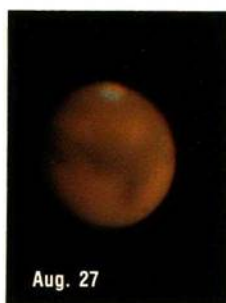
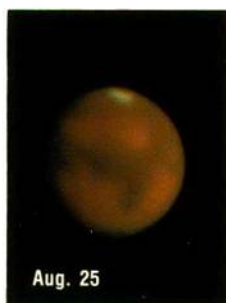
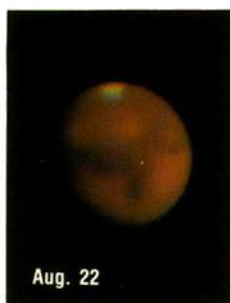
During mid-June, while U.S. observers watched the Hellas dust storm, members of Japan's Oriental

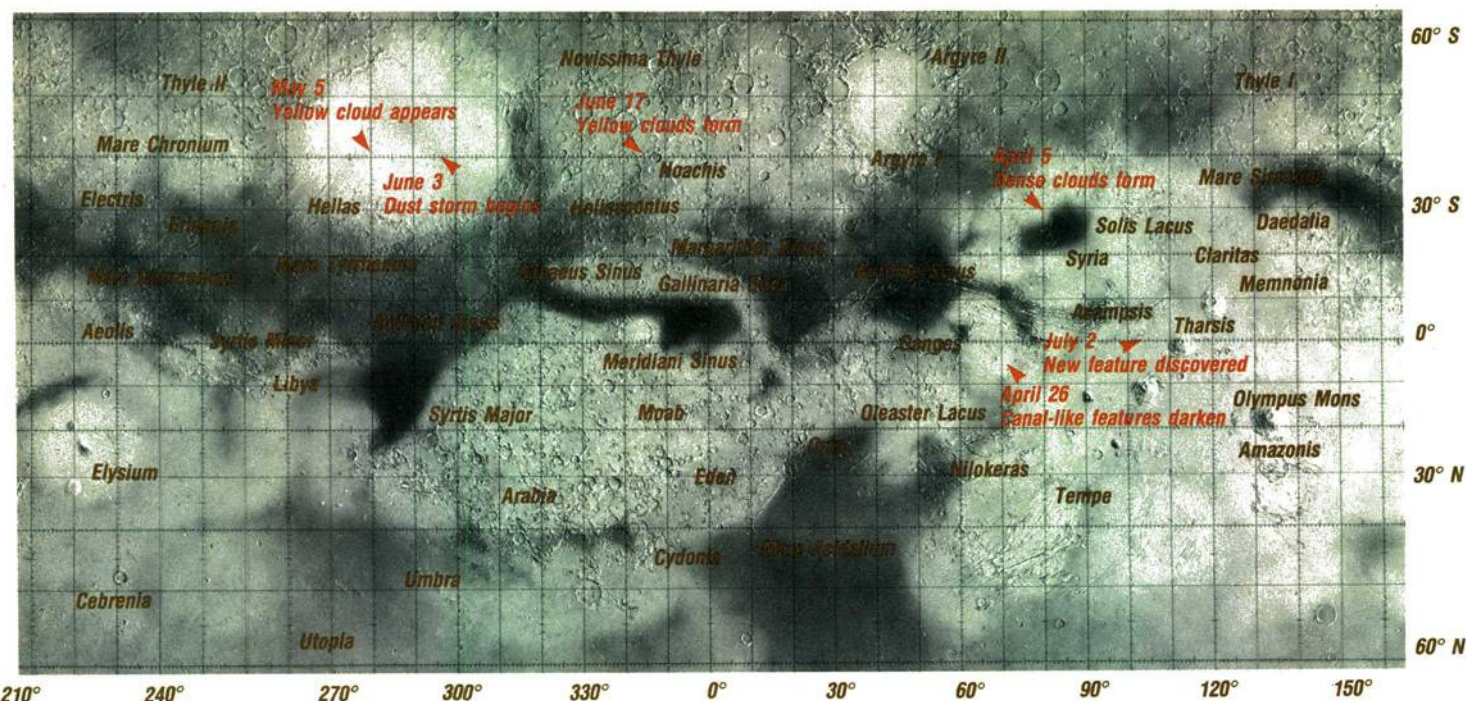
THE RED PLANET GREW in size and its surface detail became easily visible in small telescopes as Mars rapidly approached Earth between the end of July and the beginning of September. Each of these views is reproduced at the same scale and has south at top. Photos by Donald C. Parker.





THE BEST VIEWS of Mars since 1971 were captured this summer as the Red Planet passed within 36 million miles of Earth. Donald Parker's photograph, made on August 25, shows Syrtis Major, Deltoton Sinus, Mare Tyrrhenum, and a tiny detached portion of the South Polar Cap known as the "Mountains of Mitchell."





What Happened on Mars Last Summer?

April 15 Solis Lacus, the "Eye of Mars," is covered with dense clouds first spotted by Dan Troiani and Frank Melillo. Mars lies in the morning sky and measures 7.5" across.

April 26 Canal-like features Hydraotes, Lysis, and Nilokeras II, dark bands connected to Oleaster Lacus and Lunae Lacus, begin darkening substantially. This continues through June 3.

May 5 Mars observer Dave Raden discovers a yellow cloud in the Hellas basin. The cloud expands over the next two days until it extends through Deltoton Sinus and the Libya basin.

June Four features discovered by nineteenth-century astronomers Schiaparelli, Lowell, and Antoniadi become visible again during June after disappearing for years. They are Acampsis, Eosphorous, Gallinaria Silva, and Noctis Lacus.

June 3 A dust storm in the Hellas basin is observed by Gerard Teichert in France. The storm lasts until June 21, when it quickly subsides.

June 17 Japanese observer Isao Miyazaki finds yellow clouds in the Noachis and Argire I regions. By now Mars' diameter has grown to nearly 12".

June 22 Lowell Observatory astronomer Leonard Martin reports a dimin-

ished brightness of the South Polar Cap. This trend continues as springtime in the Martian southern hemisphere gradually melts the cap.

July 2 A new dark feature on Mars connecting Acampsis, Gallinaria Silva, Memnonia, and Titanium Sinus is discovered by Donald C. Parker and Jeff Beish with small telescopes. The feature is not visible on any previous Mars maps.

August 7 Stephen O'Meara, observing with the 60-inch telescope at Mount Wilson, California, traces the new feature discovered by Parker and Beish all the way to Cerberus III. The diameter of Mars now exceeds 18".

August 11 Mars at perihelion.

August 21 A minor dust storm in Hellas basin is observed by Donald C. Parker, Dan Troiani, and Dan Joyce.

August 22 The "Mountains of Mitchell," two white spots detached from the South Polar Cap, are visible in small telescopes.

September 22 Mars makes its closest approach to Earth at a distance of 36 million miles; its disk diameter is 23.8".

September 28 Mars reaches opposition to Earth and is visible high in the sky at midnight.

Astronomical Association monitored the other side of the planet. On June 17, Isao Miyazaki discovered a bright yellow cloud in Argire I. At the same time a thin veil of dust covered parts of Meridiani Sinus, Margaritifer Sinus, and Mare Erythraeum. This disturbance vanished two days later, clearing the view of Martian features. Another Hellas dust cloud became visible on August 21 but failed to develop into a major storm.

At least as exciting as tracking Martian dust storms was the opportunity to watch changes in the South Polar Cap. Because the southern hemisphere of Mars was tipped toward Earth, amateurs watched as spring progressed in the southern hemisphere and the polar cap thawed and shrank to a fraction of its earlier size.

In May Mars watchers began to notice that the South Polar Cap was diminishing in size. On June 3, Dan Boyar first observed the detachment of Novissima Thyle from the polar cap. (Novissima Thyle is an elevated ridge covered with polar cap ice.) In the weeks that followed, this feature evaporated until early July, when all that remained were two white spots called Novissima Montes. Although these spots are remnants of icy polar cap material, they are known informally as the "Mountains of Mitchell."

Altogether five American observers regularly measured the size of the retreating polar cap. Beish, Parker, Harry Cralle, Karl Fabian, and Jim Meadows completed reports on the Martian south pole region every chance they could. Eventually these observations will be combined with data from the British Astronomical Association to produce an overall picture of the South Polar Cap's behavior.



A VARIETY OF FEATURES. Michael Mattei's series of sketches shows the planet's changing features in a 6-inch Schupmann telescope at 212x (right), 381x (left), and 571x (center). On June 30 (left) Mars shows haze over its North Polar Region and an unusual dark area inside the South Polar Cap. On August 5 (center) Solis Lacus is prominent, and haze lingers over the north pole. On August 13 (right) clouds are visible over the Hellas basin (indicated by a dotted line). All drawings have south at top.



DUST STORMS. Several times last summer Mars produced minor dust storms that failed to spread over the planet. Dan Troiani sketched the most prominent storms with a 10-inch f/6 reflector at 374x. On June 18 a dust storm formed in the Hellas basin (left) but dissipated after several days. On August 12 what appeared to be a dust storm formed in the Argyre region (center); this was actually a bright spot on the planet's surface. A dust storm in the Hellas basin on August 21 (right) brightened the region considerably. The Mountains of Mitchell are visible in this sketch north of the South Polar Cap. All drawings have south at top.

Preliminary results indicate that the cap stopped melting for an abnormally long time in June and early July, its edge halting at 70° areocentric latitude. This happened at the same time large amounts of dust were observed in the Martian atmosphere, so dust suspended over the South Polar Cap may have absorbed enough sunlight to halt the rapid thaw.

When amateurs weren't watching the polar cap, they were looking for changes in Martian surface features. Throughout the summer Solis Lacus, the "Eye of Mars," was unusually dark and appeared to be surrounded by small, canal-like features. (Solis Lacus, part of a sloping, cratered ridge, is called the eye because of its round, dark appearance.) In mid-April Dan Troiani and Frank Melillo reported seeing clouds over Solis Lacus. Between April 25 and June 3 the Ganges region doubled in size and appeared much darker than usual, according to observations by Beish, Parker, and Cralle. During the same period, the canal-like features Hydraotes, Lysis, and Nilokeras II — dark linear features connected to

Oleaster Lacus and Lunae Lacus — became prominently visible. These unusual features were first observed in the 1950s by ALPO observers scattered across the country.

Changing Martian features aren't always easy to see. Several regions on the planet's surface became less prominent or showed less detail than they have in the past. West of Solis Lacus lie regions called Daedalia and Claritas. Dark and prominently visible during the 1970s, these areas appeared much lighter (and more difficult to see against the Martian surface) last summer. Similarly, details in Mare Sirenum have appeared washed-out and difficult to see.

The great surprises of this year's Mars apparition were the rediscoveries of four dark features originally identified in the nineteenth century by Giovanni Schiaparelli, Percival Lowell, and Eugene M. Antoniadi. In June Beish, Parker, Miyazaki, Boyar, and Stephen J. O'Meara identified Acampsis, Eosporous, Gallinaria Silva, and Noctis Lacus. Acampsis is a dark spot north of the Claritas region. Eosporous is a long, dark streak run-

ning from Solis Lacus down to the Tharsis ridge. Gallinaria Silva is a dark irregular feature near Noachis. Noctis Lacus, a round dark feature, lies just south of Valles Marineris.

On July 2, Beish and Parker discovered a new feature: a lane swept clear of dust that appears like a long, twisting dark line on the planet's surface. The feature begins as a westward extension of Acampsis, connects to Gallinaria Silva, and crosses Memnonia to Titanum Sinus. Slightly over one month later, O'Meara observed the feature with the 60-inch telescope at Mount Wilson and traced the feature as far as Cerberus III.

The first half of the 1988 apparition of Mars brought the opportunity for thousands of people to get their first good look at Mars. The easy visibility of the planet throughout each evening and its placement high in the sky enabled just about anyone who wanted a look to get one. And through mid-September, amateurs were spared the obscuring effects of a planetwide dust storm, something feared as the apparition's demise but also something that hasn't so far shown up. □

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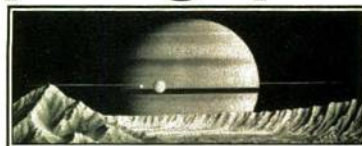
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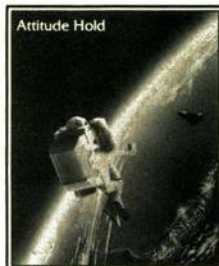
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Optical Illusions of Low-Angle Observing

Watch for a squashed Sun, the green flash, Venusian haloes
— all results of atmospheric distortion.

by Leendert de Witte

Remember the last time you watched the Sun set over a flat, clear horizon? As the Sun set, it flattened and turned slightly red. Its image then became distorted, almost as if the Sun were melting into a rippled mass of deep orange wax.

Earth's atmosphere alters the way we see celestial bodies. The atmosphere's distorting effects are most pronounced when celestial objects approach the horizon and we look at them through a long, dense column of atmosphere. (The light from an object low in the sky may pass through hundreds of miles of air before reaching us.) Therefore, the best time to see atmospheric effects is when objects rise or set.

Images of stars and planets low in the sky are distorted in several ways. Earth's atmosphere bends rays of light, which causes objects to appear higher in the sky than they really are. The different colors of light in the setting Sun's image are bent by different amounts and produce a "green flash" of light as the Sun disappears in the west. And sunlight bounced through raindrops produces a rainbow.

The images of all celestial objects are affected by the atmosphere. Because of their great brightnesses, however, the Sun, Moon, and bright planets are most obviously affected. These effects are visible to a lesser degree when you observe stars.

You don't need a telescope to see the atmosphere's effects. A number of these effects like rainbows, the scattering and absorption of sunlight, and the strong refraction of the Sun are visible to the naked eye. In general, when the Sun is shining low in the sky and it is raining, you can see a rainbow. All you need do is look in the direction opposite the Sun's position in the sky.

Sunlight effects are all around us. The sky is blue because sunlight is scattered throughout Earth's atmosphere. Absorption of sunlight by dust or other particles in the atmosphere causes ruddy sunsets. And absorption of light from the Sun's disk and refraction by the atmosphere conspire to produce a squashed, deep red Sun as it approaches the horizon.

To see other effects well, you'll need to employ some optical aid. If the Sun appears dim, take a brief glance at it with a pair of binoculars as it rises or sets — but make absolutely sure that its image is faint enough so you don't damage your eyes. You can take longer looks at refraction and absorption effects in the Moon's rising or setting image.

Binoculars are useful for spotting and studying other

types of low-angle phenomena. If the Sun's image is pale as it rises or sets, take a pair of 7x50 or larger binoculars with you at sunrise or sunset. To steady the binoculars, you may need to mount them on a tripod. Also take along a sketch pad or sheets of paper and a pencil. Choose an observing site with a flat, unobstructed horizon toward the east (sunrise) or west (sunset). As the Sun's flattened image drops down to the horizon or rises out of it, make a sketch of the distortion you see along the Sun's limb. You'll be amazed at the effect refraction has on the Sun's image and the way these distortions vary with each sunset and sunrise. (Note: Before looking at the Sun directly, be absolutely sure the Sun's image is faint enough not to harm your eyes.)

With a telescope you can follow bright planets like Venus and Mercury as they rise out of the murk or set after traversing the sky. You will see unusual color effects in the images of these planets.

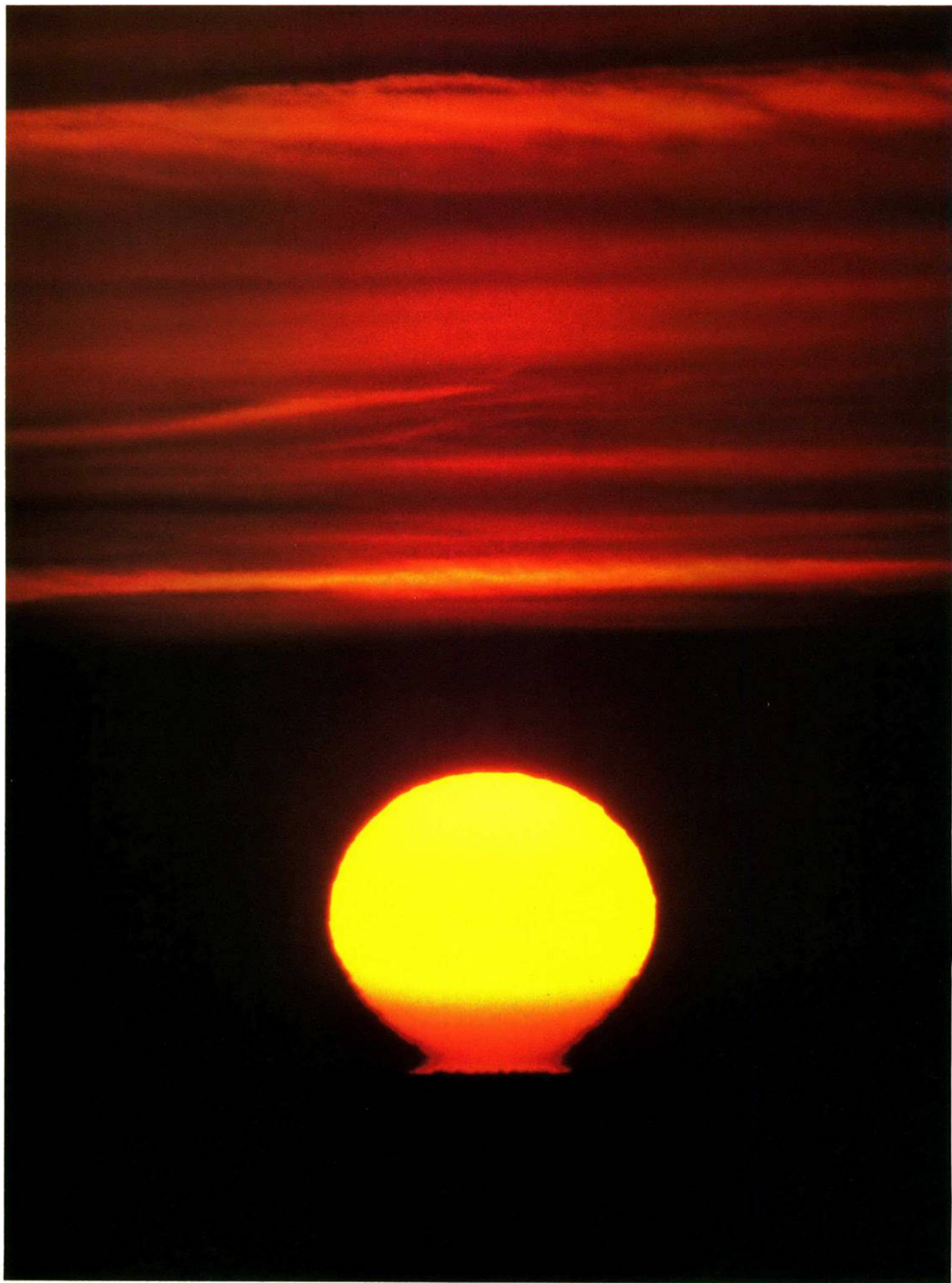
Refraction, the cause of unusual color effects and the flattening of the Sun and Moon, is the most significant effect caused by Earth's atmosphere. When light passes from one medium into another, it bends. You can see refraction clearly by placing a pencil into a glass of water. The pencil appears to be bent. It isn't, of course: light rays passing into the water and emerging from the water bend as they go from a less-dense medium (air) into a denser one (water) and back out again.

The same effect occurs when sunlight and starlight pass from space into the atmosphere — in the last split seconds of a journey that may have lasted hundreds of thousands of years between a star and your eye. And this effect determines how you will see the star.

Refraction causes objects low in the sky to appear higher than they are. This is because light rays from the star bend downward as they enter the atmosphere. The difference between reality and illusion can be considerable: at sunset or sunrise the Sun typically appears to be one full diameter higher in the sky than it is.

Unusual color effects are also produced by refraction. As light from an object is bent, certain wavelengths (colors) are bent more than others. The result is a spreading out of colors like that produced by a prism. For

ITS LOWER EDGE RAISED BY REFRACTION, an oval, flattened Sun slowly sinks in the west. Refraction and other atmospheric effects dramatically change astronomical objects as they approach the horizon. Photo by Roger Browne.



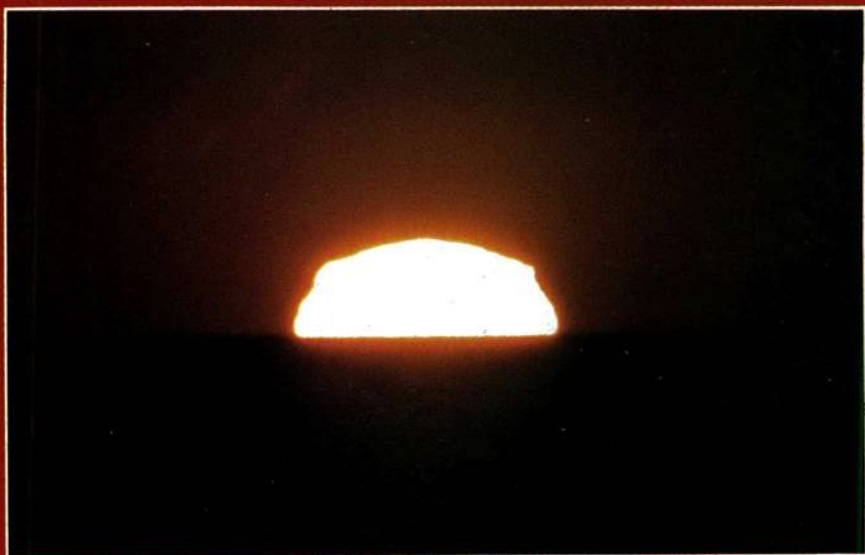
Light Bends in Funny Ways

If you stop and look, you can see refraction every day. Stick your leg in a bathtub full of water and your leg will "break" where it enters the water. Sit by a swimming pool on a sunny day and you'll see sharp patterns of sunlight wildly dancing on the bottom of the pool as the water splashes back and forth. These are examples of refraction, a property that describes how light (or other radiation) changes direction as it passes from one medium into another of a different density.

Refraction dramatically affects the appearance of celestial objects as their light passes from one medium, space, into another of different density — Earth's atmosphere. Refraction flattens the image of the Sun as it sets or rises (opposite page, top).

The diagram on the opposite page shows how light of different colors bends in different degrees as it enters the atmosphere. This spreads out various colors of light in the same way a prism does, which gives the Sun, for example, a red rim at its bottom and a green rim at its top. This effect is visible in the photograph of Venus (opposite page, bottom right).

Refraction also causes the "green flash" when the Sun sets over a clear, flat horizon (this page). The last part of the Sun visible is the green rim, so a moment before the Sun's image slips away it sometimes produces a flash of green light.



A FLATTENED SUN SINKS into the horizon. . .



. . . continues sinking . . .

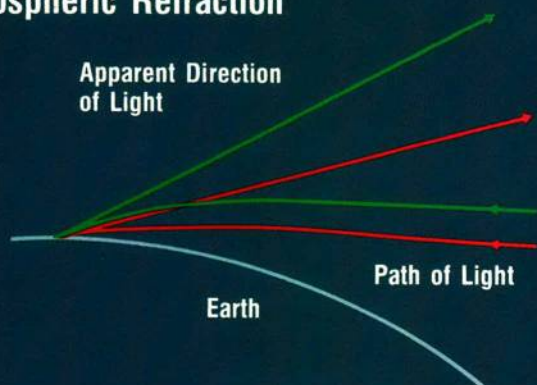


. . . and disappears with a "green flash." Photos by L. Eduardo Vega.



REFRACTION FLATTENS AND DISTORTS the Sun and separates its colors: green on top and red on the bottom. Photo by Leendert de Witte.

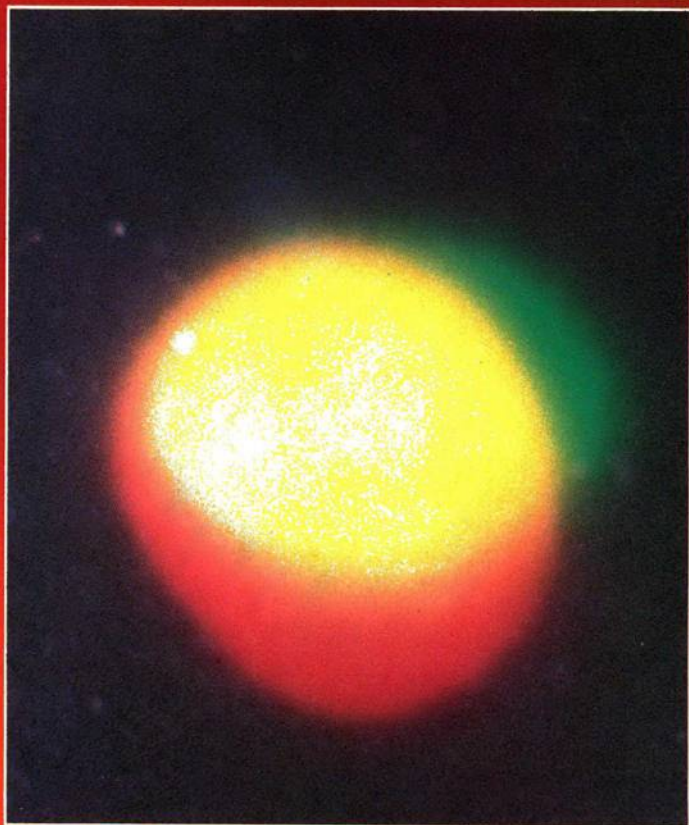
Atmospheric Refraction



Light rays bend as they enter the atmosphere. Blue light is scattered in the atmosphere, but green and red pass through at slightly different angles.



The result for an observer on Earth is two overlapping images of an object, green on top and red on the bottom.



AS VENUS SETS, refraction shifts the planet's green image upward and its red image downward. Photo by Leendert de Witte.

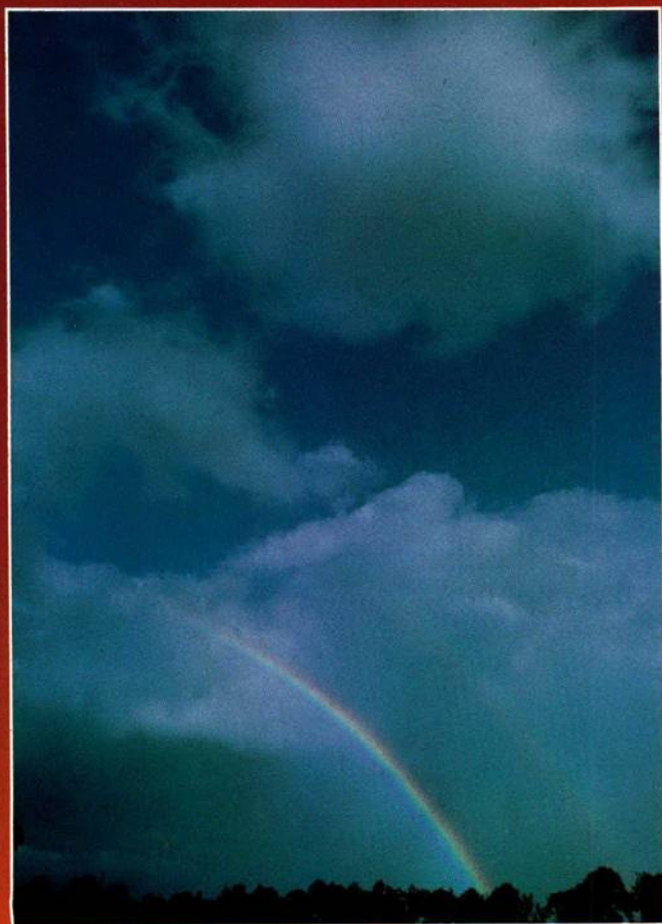


SUNLIGHT AND WATER DROPLETS form a multicolored rainbow over Paris. Photo by Olivier de Goursac.

What Makes a Rainbow?

Refraction is also responsible for creating rainbows. A rainbow forms when sunlight illuminates water droplets in the atmosphere. The water droplets separate the sunlight into its spectrum of individual colors by the process of double refraction. First, sunlight is refracted by the front of a given raindrop. It then reflects off the back side of the raindrop and is turned around. Then the light ray is refracted again through the front of the raindrop, thereby separating sunlight into its component colors. (See diagram.)

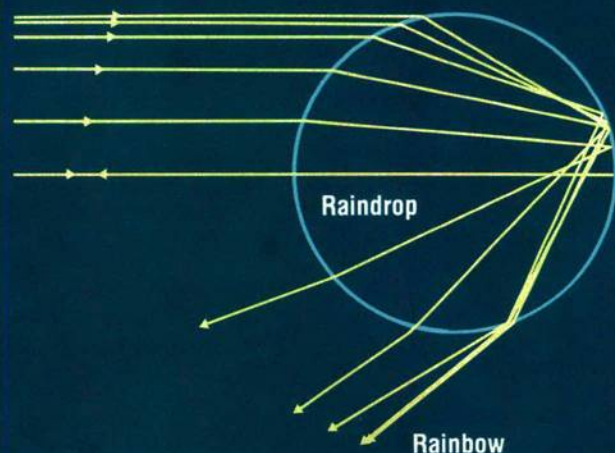
This process forms a semicircular rainbow like the one over Paris (left). Rainbows are visible if observers face away from the Sun; they are centered on the imaginary antisolar point. Because the light rays entering and exiting raindrops concentrate at a certain angle, rainbows appear as circular rings with diameters of 84° , and they are usually broken by the ground. If a second layer of water droplets, which produces a different angle of reflection, exists, it can contribute to a secondary rainbow. The photo (bottom left) shows a secondary rainbow that is characteristically fainter than the primary.



A DOUBLE REFLECTION inside a water droplet produces a double rainbow. Photo by David Rights.

A Question of Angles

Sunlight



A rainbow is always a circle with a radius of 42° centered on the anti-solar point. This happens when sunlight emerges from raindrops at an angle of 42° from the direction the sunlight entered.

example, as the Sun sets, blue light in its image is bent more than green light and green more than red. Different colors of light appear to come from slightly different elevations. The image of the Sun formed by its green light component appears slightly higher than the solar image formed by its red light component.

You can see this separation of colors in the setting Sun. Most of the Sun's blue light is scattered in the atmosphere and some of its yellow light can be absorbed by water vapor. The result is, that of the surviving colors, red and green dominate, and green is the last to slip under the horizon.

Color separation by refraction causes green and red rims. When the setting Sun is still well above the horizon, at an altitude of 10° or so, a greenish ring is sometimes visible around the Sun's periphery. As the Sun continues to set, the green color becomes more pronounced in the upper limb, while the lower limb reddens slightly.

The red and green coloration may not occur exactly at the "top" and "bottom" of the Sun as you see it. A line connecting the centers of the colored rims may in fact deviate from being vertical by as much as 45° . Low-angle images of Venus may also show a tilt in red and green color bands as the planet's disk approaches the horizon.

The most spectacular of all refraction phenomena is the green flash. In a clear atmosphere, as the Sun disappears below the horizon, the last light visible is the upper segment of the green rim. After the Sun's disk is gone, this green rim is visible for an instant, without the rest of the Sun's image, as a flash of green light. The clearer the atmosphere, the more brilliant the flash. This phenomenon is only visible over an extremely flat horizon. You may not see it every time you look for it. But when you do see the green flash, you'll know you have seen one of the most unusual sights in the sky.

Refraction is critically affected by the atmosphere's density. The density of Earth's atmosphere normally decreases exponentially with height above sea level. When refraction occurs between layers of air with different densities, the images of distant objects are distorted. Some parts of the image appear enlarged and others shortened or turned upside-down. A good example of this distortion is the "Chinese lantern" appearance of the setting Sun. This is when the flattened Sun appears to have distorted "fingers" and other small distorted features around its edges.

If atmospheric conditions are right, refraction causes mirage effects. When air density decreases with height, a ray of light entering the atmosphere is curved slightly downward. To an observer, the light ray's point of origin appears somewhat higher in the sky than it really is. The reverse happens when air density increases with height, which occurs when air near the ground is significantly hotter than the air above it. Light rays from an object like the Sun are then bent upward, which causes the Sun to appear lower than it is. In this instance, light rays initially pointed downward curve to near horizontal, pass through a minimum altitude, and move in an upward direction. Let's say one of these rays begins on the lower limb of the Sun's disk. A second ray, starting from a somewhat higher point, takes longer to level out and curves upward more steeply. It appears to be coming from a lower point than the "flatter" ray. Therefore, the image formed in an observer's eye is an upside-down view of the Sun that appears lower in the sky than it is.

This is called an inferior mirage.

A superior mirage is the result of warm air moving over a cold lake or ocean. This creates an inversion layer, a "sandwich" of atmospheric layers. An inversion layer consists of a layer where temperature decreases with height below a layer where temperature increases with height, and this in turn lies below a layer where temperature decreases with height. The result is a stable atmosphere consisting of a hot air cushion sitting on colder air. The cold ground or water under this layer cools air near the ground. This causes light rays to be bent downward and therefore makes objects appear to be higher in the sky than they are.

At sunset, multiple superior images can be observed at the top of the Sun's disk, forming and vanishing as the Sun sinks into the lower atmosphere. Superior mirages usually appear as green rings on the upper limb of the Sun. A rainbow is one of the most familiar refraction effects. This colorful spectacle results from sunlight refracting through water droplets and reflecting outside again. The refraction separates sunlight into its component colors, and the reflection off the "back side" of each water droplet that follows redirects the image to observers who face away from the Sun. A single reflection in each water droplet causes a single rainbow. Multiple reflections can create weaker second and even third rainbows, each reflection reversing the order of the colors. Any time when it's raining and the Sun is shining, look 180° away from the Sun and you may see a rainbow.

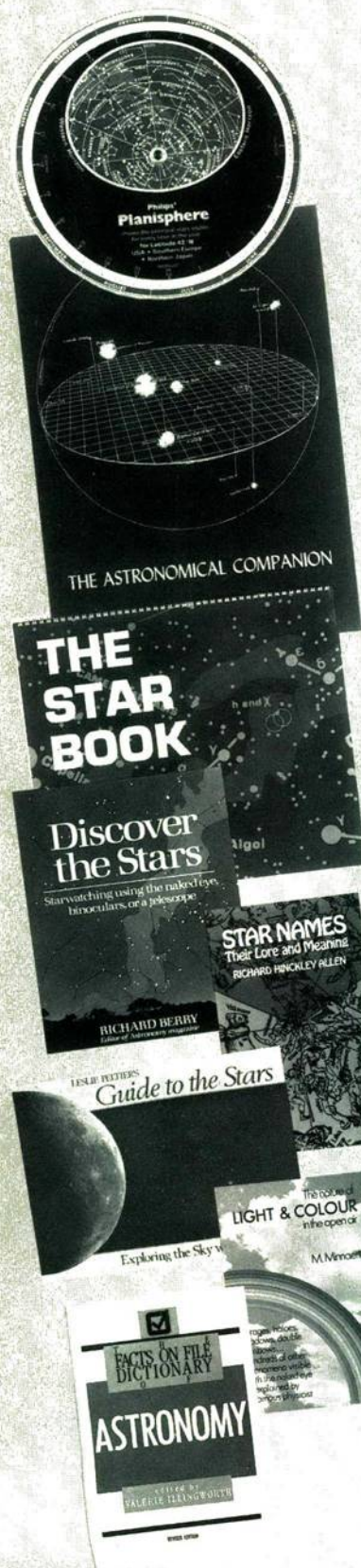
Absorption and scattering also play a role in forming the images you see. Absorption of light rays in the atmosphere occurs when certain wavelengths of sunlight or starlight are taken in and not reflected by the atmosphere. Absorption diminishes the intensity of an object's color, so the color appears more like the white light of the Sun. Scattering randomly distributes light as it bounces off atmospheric particles. For example, smoke or haze suspended in the atmosphere may cause the Sun's image to appear deeply ruddy. By scattering or absorbing most of the Sun's blue and green light, diffuse red borders may be seen around the images of the Sun when it's low on the horizon. This may happen with the Moon as well.

Also caused by suspended matter, the "sunburst effect" was noticed by American Indians many centuries ago. This happens when a combination of the Sun's rays are reflected and absorbed by scattered clouds, while beams of sunlight that pass through the clouds are made visible by reflection in water droplets and dust. The result is a fan-shaped spike of light extending from the Sun up toward the zenith.

Whether you're glancing at the big red image of the Sun as it sets, the Moon rising over a distant mountain, or Venus through a telescope, think about the fact that you're not seeing celestial objects as they are but as the atmosphere will let you see them. Understanding the effects produced by Earth's atmosphere can enhance your appreciation of why the universe looks the way it does. □

A native of Holland, Leendert de Witte holds a doctorate in geophysics from the California Institute of Technology. His job as a consultant for oil companies in Baja California offers dark skies for astronomical observing.

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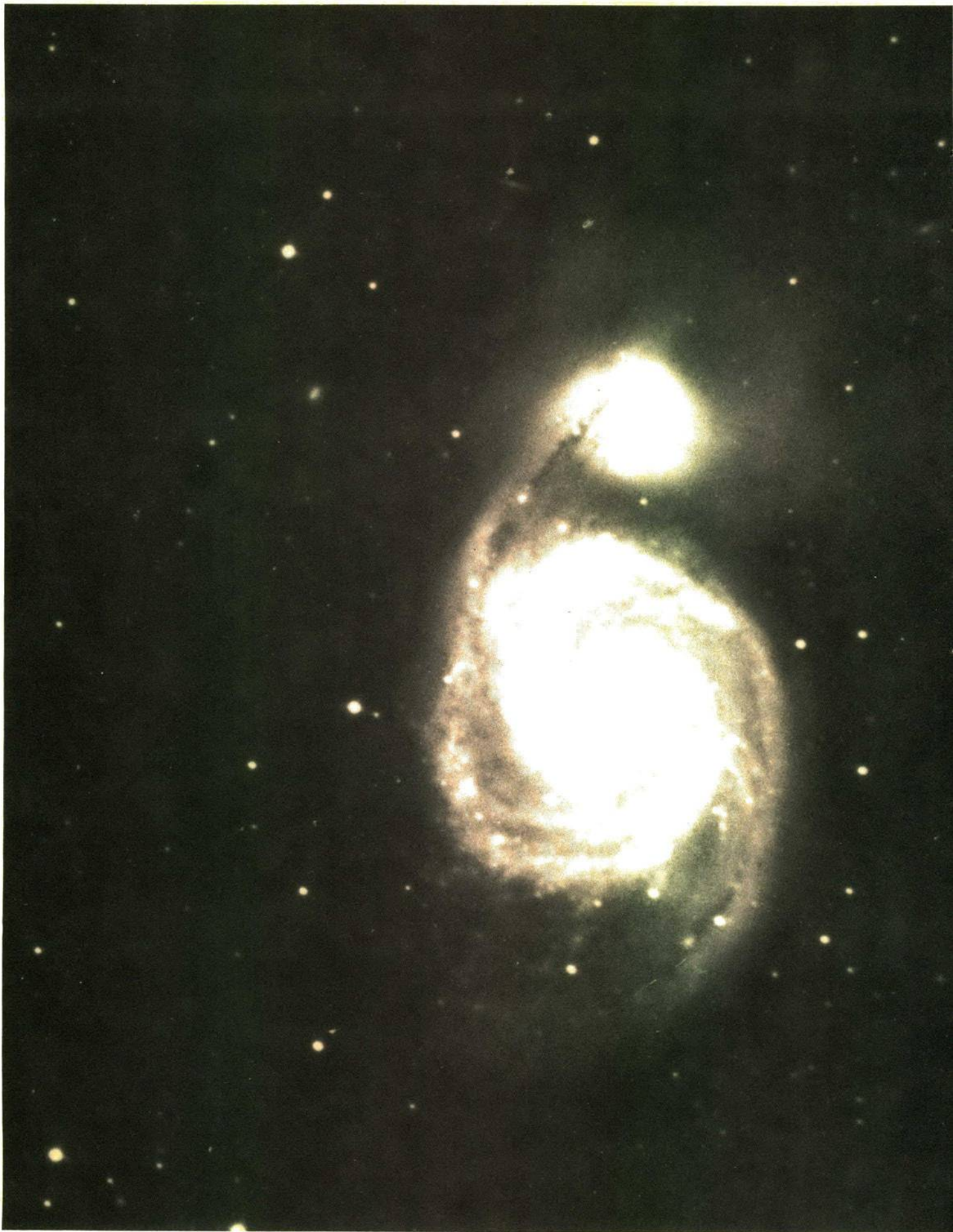
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Galactic Collisions on Your Computer

Create bridges, rings, and whirlpools through
the gravitational interactions of colliding galaxies.

by Michael C. Schroeder and Neil F. Comins

The universe contains billions of galaxies, each with hundreds of billions or even trillions of stars. Galaxies are not isolated objects; most of them are found in gravitationally bound groups called clusters. Because of this clustering, it is common for galaxies to pass close enough together to gravitationally distort one another. Astronomers have seen thousands of such systems. One of the most famous examples is the interaction between M51 (the Whirlpool Galaxy) and NGC 5195. Some astronomers even suggest that the Milky Way has been warped by near passes of the Magellanic Cloud galaxies.

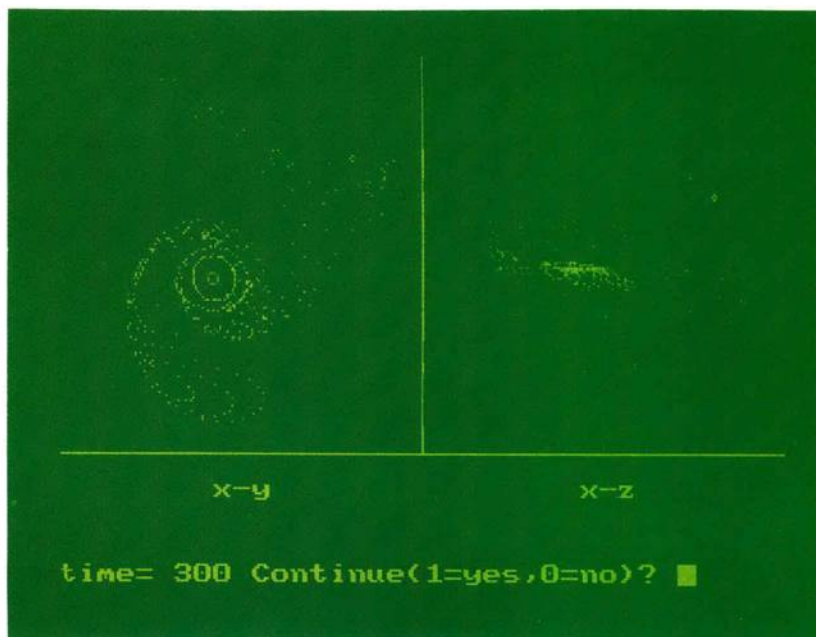
We have written a computer program called Galaxy Collisions in 3 Dimensions (GC3D) that simulates the gravitational interactions between galaxies in which one of the galaxies is

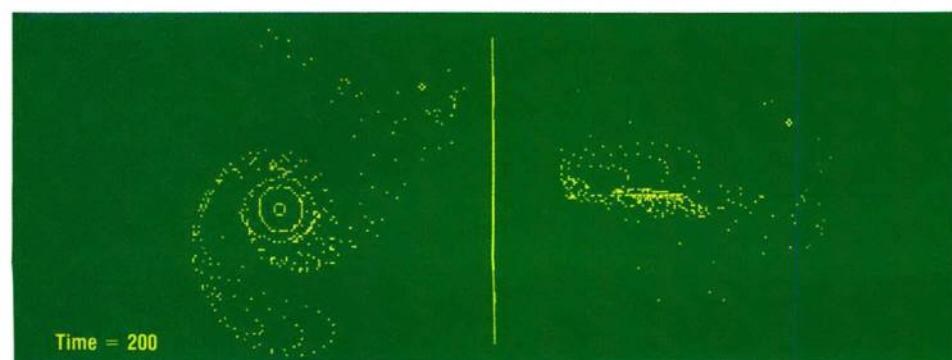
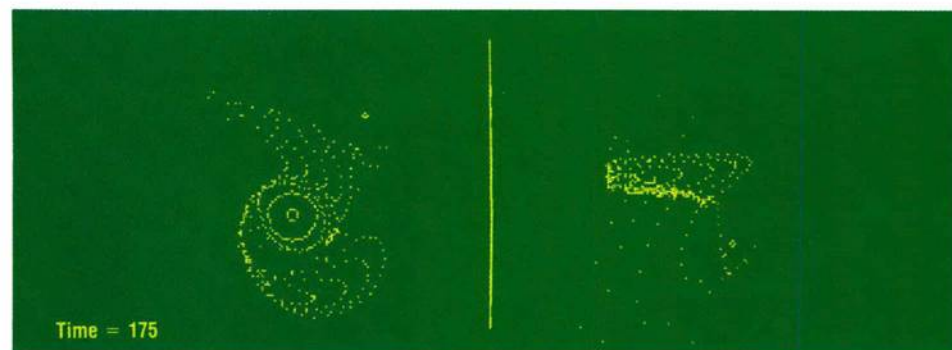
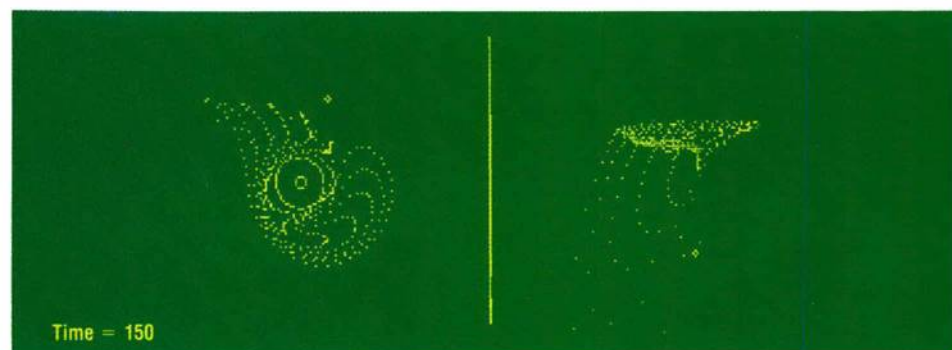
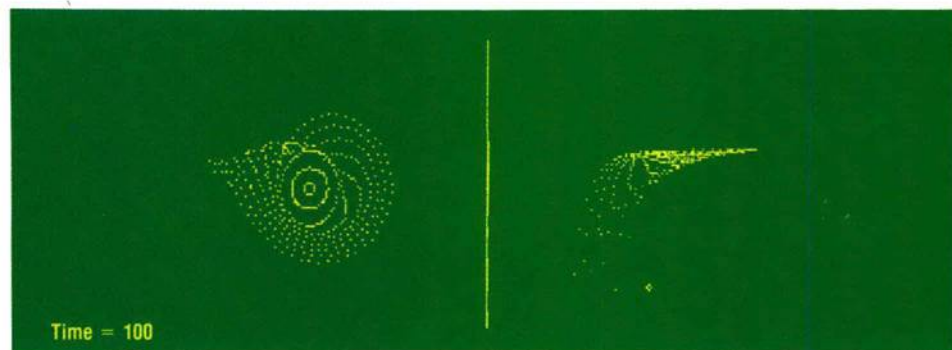
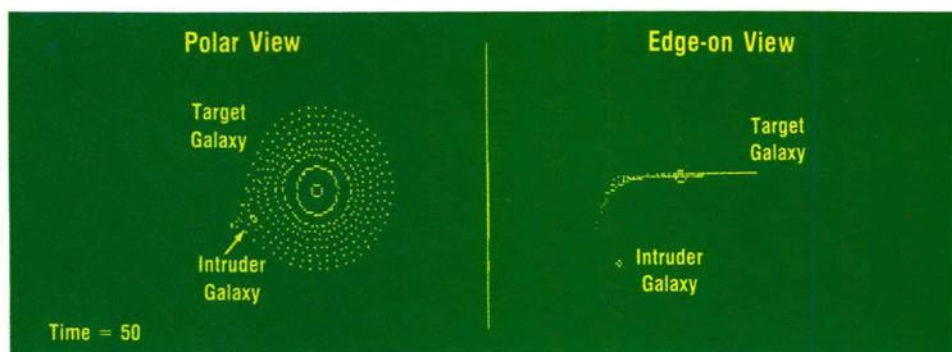
a disk, like our Milky Way. Our program allows you to explore the dynamics of galaxy collisions and to modify the interactions between galaxies to derive impressive and perhaps insightful results, including phenomena such as intergalactic bridges, rings in and around galaxies, and "rat-tails" between interacting galaxies, all of which have long piqued the interest of astronomers. Although the program is written in BASIC to run on IBM-PC computers and compatibles with graphics capabilities, it is easily converted to other systems.

The Basics of Colliding Galaxies

Astronomers are still exploring the effects that galactic collisions and near misses may have on individual galaxies. Even fundamental questions like "Does an interaction change the overall structure of a galaxy?" and "Can a

SIMULATE GALAXY COLLISIONS like the Whirlpool Galaxy interaction (left) on a personal computer (below). Photo by K. A. Brownlee.





AN INTRUDER GALAXY edges past the target galaxy, distorting a spiral arm. The result is an M51-like interaction.

galaxy change from a spiral to an elliptical?" have not been completely answered yet. Of course, observationally we just see snapshots of the universe; over the hundred years or so that we have taken photographs of galaxies, the relative motions of galaxies have been minuscule as seen from Earth. So how do we make the connection between reality, as shown by fixed images, and theory, as given by evolving equations? We convert the equations into computer simulations that provide many "snapshots" that can then be compared with direct images and spectra of galaxies.

The enormous complexity of real galaxies — whether disk, elliptical, or irregular — presently makes detailed collision simulations intractable, even on the most powerful computers. Many activities in real galaxies, such as star formation, stellar evolution, spiral density waves, magnetic fields, interstellar gas flows, dark matter, planetary systems, binary stars, central and other black holes, and globular clusters, conspire to affect galactic structure and, therefore, the images and spectra we take.

However, as you will see in the simulations you can run with this program, gravity is responsible for most global galactic structure. And because gravity is relatively easy to simulate, most computer models of galaxies focus exclusively on gravitational effects, ignoring all other factors. Even so, the best models only use a few hundred thousand particles to represent the motions of billions of stars (our Milky Way contains over 100 billion stars). On Cray 1 X/MP-class computers the program runs take the central processor several tens of minutes.

To appreciate how far computers have advanced in the last few years, consider that the first simulations of colliding galaxies were done in the early 1970s on a state-of-the-art mainframe and required from 5 to 10 min-

utes to run a collision with only 350 particles. Today with an IBM PC-AT and compiled BASIC our program can reproduce the same collisions with the same number of particles in the same amount of time. In addition, the results of the collisions here are displayed in real time on the computer screen, a convenience not easily available to early researchers.

Fitting Galaxies in a Computer

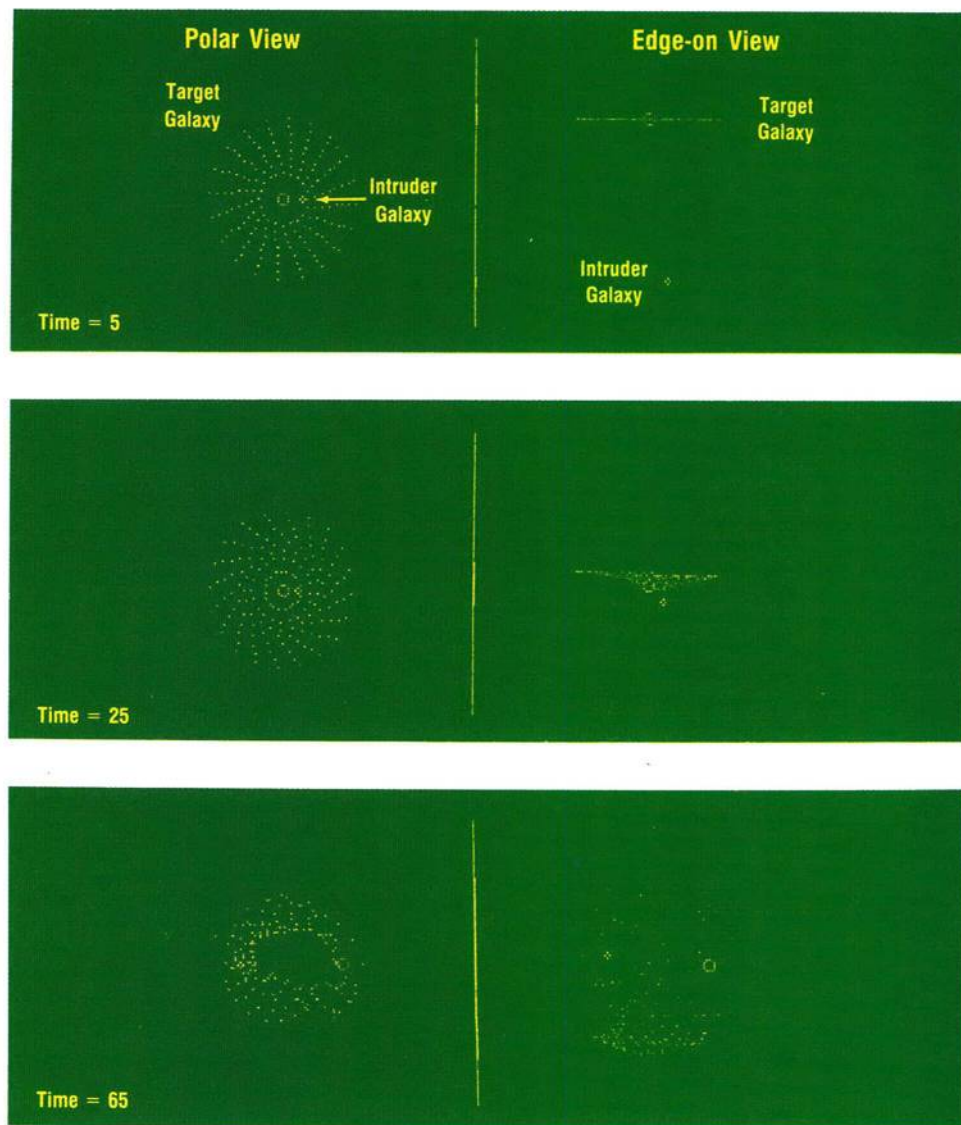
Prominent among the numerical techniques in galactic gravitational studies are the N-body programs. These are programs designed to determine the trajectories of a number of collisionless bodies — N-point masses — when only gravitational interactions are considered. Depending on the number of particles in a particular simulation, each N-body particle represents a hundred million or more stars. N-body codes calculate the gravitational force between two or more particles and move them accordingly.

In a now-classic 1972 set of N-body experiments, Alar and Juri Toomre showed that many of the global features of interacting galaxies were due to gravitational tidal effects and not to magnetic fields or unknown repulsive forces as some astronomers had previously postulated. Tidal forces occur when an object is so large that the force of gravity from an external (or small internal) source varies across the object. For example, the tidal effect of the Moon on Earth causes our tides. Similarly the tidal effect of galaxies on one another causes the nearby parts of the galaxies to be pulled most, leaving the more distant parts behind.

Many more sophisticated and powerful N-body programs have been developed since the Toomres did their work in this field; however, the newer works require much more memory and speed than are currently available in PCs (unless you are willing to let your machine run for days at a time).

Our program employs the same N-body approach used by the Toomres. The target disk galaxy consists of a central mass and a set of massless test particles distributed in a disk around it. The number of test particles is adjustable in the program. The more you use, the more detailed the effects you see. The intruder galaxy is a single mass point. It may be any type of galaxy: disk, barred, elliptical, or irregular. (A feature programmers may wish to program into GC3D is making the intruder a disk and giving it a set of test particles. Similarly, the target can be given other test stars to create an elliptical galaxy.)

Instead of calculating the individual interactions between hundreds or



thousands of N-body particles to move the systems, we pretend that the total mass of each galaxy is at the galaxy's center and move the two central masses as a result of only their interaction. Lines 870 through 950 in the program do that. After the galaxies move, we calculate the effects of both centers on the disk particles. This is done in lines 720 through 860.

But wait a minute, you say, that seems logically inconsistent. Why don't the disk particles gravitationally affect the other galaxy? The answer is that the disk of stars in our Galaxy represents a small fraction, 10 percent or less, of the galaxy's total mass. Therefore, the gravitational influence of the disk stars on the companion galaxy is relatively low. The important thing to note is that for each time step the motion of the disk stars is affected by both central masses. The gravitational effects of the disk stars on one another is, again, relatively small.

This point about using the disk stars as tracers of the relative gravitational fields of the two galaxies — and not



A HEAD-ON COLLISION between two galaxies results in a ring galaxy like the Cartwheel (above).

using the disk stars as self-consistent gravitational sources — deserves further comment. It is true that most contemporary research-grade N-body programs, including our own, calculate the mutual gravitation of the disk stars. However, when no other particles or forces are used, N-body systems initially similar to our Galaxy always evolve into bars. Barred spirals certainly exist, and they may indeed be systems with little mass other than that in the disk stars, but there are also many disk galaxies that do not have bars. What then? Theorists believe that as much as 90 percent of the mass in such galaxies is in places other than the disk, such as in massive central black holes or massive, dark haloes. It is this latter group of galaxies that we simulate here when we move the galaxies based on the gravity of the central particle alone.

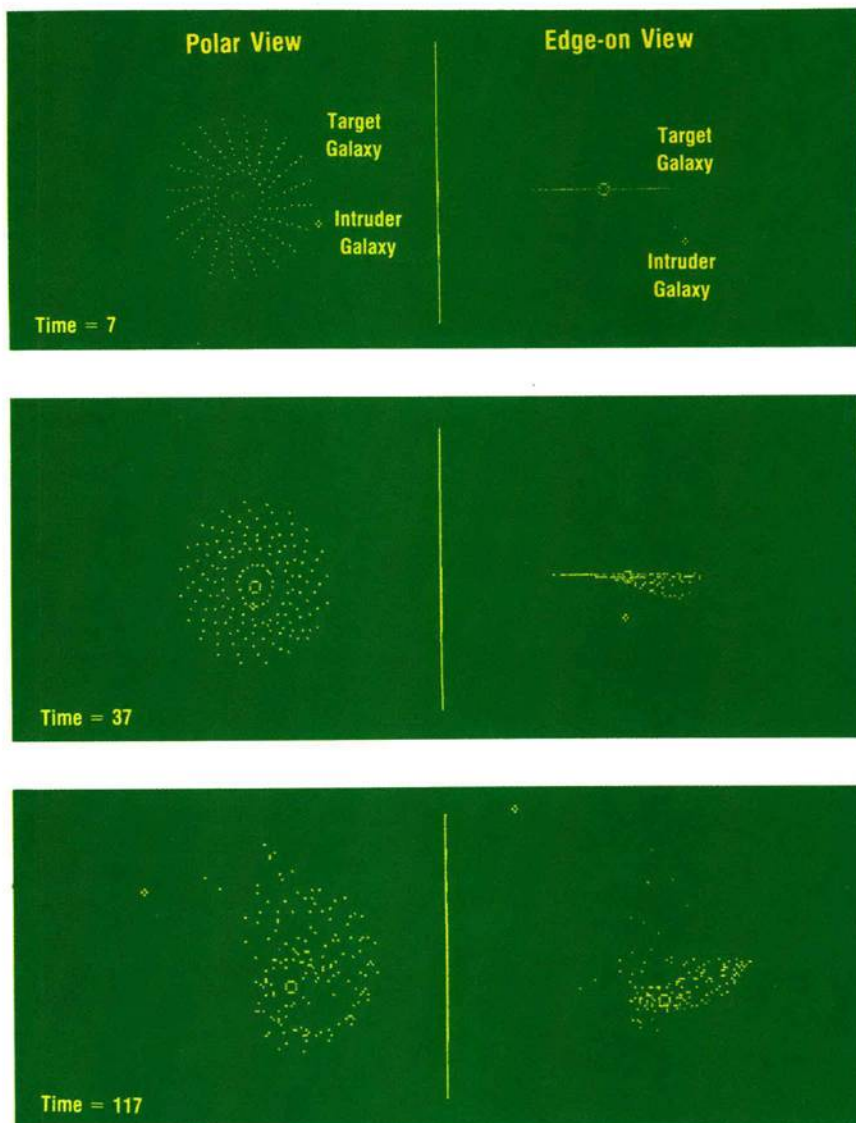
How to Use GC3D

The program begins by asking you for the intruder galaxy's mass, position, and velocity. The self-consistent units for the gravitational constant, time, distance, and mass presently used in the program are given in Table 1. The target galaxy has a mass of 5 mass units (M.U.) and a radius of 30 distance units (D.U.) and is at rest at the center of the Cartesian coordinate system with coordinates $x = y = z = 0$ (program line 360). The test stars in the target orbit in the x-y plane (program lines 460-530) and are initially set in circular, counterclockwise orbits as seen from above (program lines 560-590). The circular velocity is calculated in program lines 420-440.

The graphic output provides you with both top (x-y) and side (x-z) views of the galaxies as the run evolves. To get a hard copy output of the graphic display, load the DOS program GRAPHICS into your computer *before* loading and running GC3D. While GC3D is running, hit the *Print Screen* key. Our graphics subroutine, specific to GW BASIC, is in lines 1010-1250. Most of the effort to get GC3D working on other computers will be in this section of the program.

Each time you run the program, you will also be asked for the number of rings of test stars and the number of test stars per ring. The more test stars you use, the longer each time step takes. With few enough test stars and a fast enough PC, you can get movie-speed evolution. On the other hand, by including more stars and/or rings, you can get more detailed tidal distortion information. Always compromises.

The simulations on pages 92-94 will help you verify that your program is

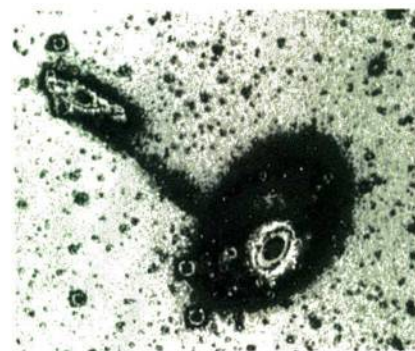


working properly. Table 2 provides the initial conditions for three types of collision results: ring, bridge, and whirlpool galaxies. There is an infinite number of initial conditions you can use. Needless to say, those of us in the colliding-galaxy business probably haven't seen every phenomenon this program can create. For example, all spiral runs that have been observed to date have trailing arms. This means that the sweep of the spiral arms from the center arches in the direction opposite the motion of the stars.

However, some simulations we are performing now suggest that at least some spiral galaxies may have first developed leading spiral arms, which then quickly converted to trailing arms. Granted that the lifetime of leading-arm spirals is a small fraction of the galactic rotation period, how can this type of spiral be created at all? One possibility is that a companion galaxy with a suitable trajectory will create tidal distortions that drive leading-arm spirals.

How the Program Works

A fundamental tenet of the law of



A BRIDGE OF NEW STARS, evident in the Toadstool Galaxy (above), is created when material is drawn out of one or both galaxies during an interaction.

gravitation states that the force of gravity falls off with the square of the distance between any two objects. However, applying the inverse square of the distance poses a problem when two galaxies are so close together that the magnitude of the gravitational force becomes larger than the computer can handle (the denominator

Galaxy Collisions in Three Dimensions

```

10 REM Galaxy Collision Program
15 REM by M.C.Schroeder and Neil F. Comins
20 REM This program allows 2 galaxies to interact via
25 REM their gravitational fields. The TARGET galaxy
30 REM is a disk and the INTRUDER galaxy is
40 REM treated as a point (it could be any type of real
45 REM galaxy). The dimension statements below
50 REM allow up to 1000 particles. You can
60 REM use more than 1000 by redimensioning these arrays.
70 REM
71 REM For proper hardcopy output,
72 REM install GRAPHICS from DOS first.
73 REM Then use 'printscreen' key(s) to save screen.
74 REM
80 DIM X(1000),Y(1000),VX(1000),VY(1000),Z(1000),VZ(1000)
90 CLS
100 REM
110 REM The stars are distributed
115 REM in the TARGET galaxy (only) in rings
120 REM The total number of stars
125 REM is the product of the # of rings and
130 REM the # of stars per ring
140 REM
150 LOCATE 1:PRINT"Input the # of rings of stars ";
155 PRINT"in the TARGET galaxy: ";
160 INPUT "",NRR
170 LOCATE 5:PRINT"Input the # of stars per ring ";
175 PRINT"in the TARGET galaxy: ";
180 INPUT "",NRS
190 NS=NRR*NRS:DR=20/(NRR-1)
200 LOCATE 9:PRINT"Input mass fraction ";
202 PRINT"of INTRUDER galaxy in units of ";
204 PRINT"the TARGET galaxy mass: ";
210 INPUT "",M2
220 LOCATE 13:PRINT"Input the initial X,Y,Z ";
225 PRINT"coordinates of the INTRUDER galaxy:"
230 PRINT"The TARGET galaxy is located at 0,0,0. ";
240 INPUT "",X2,Y2,Z2
250 LOCATE 17:PRINT"Input the initial X,Y,Z ";
255 PRINT"velocities of the INTRUDER galaxy:"
260 PRINT"The TARGET galaxy is initially at rest. ";
270 INPUT "",VX2,VY2,VZ2
280 REM The position of the TARGET galaxy
285 REM is assigned by the computer.
290 REM
291 LOCATE 21:PRINT"Input # of time steps ";
292 PRINT"for this run: ";
293 INPUT "",NTSPR
300 LOCATE 24:PRINT"Are these inputs correct ";
305 PRINT"(1=yes,0=no): ";
310 INPUT "",ANS
320 IF ANS<>1 THEN 90
330 SCREEN 1,0,0
340 LOCATE 12:PRINT"      Thinking...."
350 REM rem initialize TARGET galaxy mass,
355 REM position and velocity.
360 M1=5:X1=150:Y1=100:VX1=0:VY1=0:Z1=0:VZ1=0:SF2=2
370 REM scale the INTRUDER galaxy mass,
375 REM position and velocities.
380 TIME=0:M2=M2*M1:X2=X2+X1:Y2=Y2+Y1:Z2=Z2+Z1
390 REM set up initial load
400 REM place stars in concentric rings
405 REM from r=10 to r=30 at
410 REM intervals of dr
420 FOR IR=1 TO NRR
430 R=10+(IR-1)*DR
440 V=SQR(M1/R):TH=(.5*V/R)*(180/3.14159)
450 IF R=10 THEN V=.9*V
460 FOR IT=1 TO NRS
470 T=(IT-1)*360/NRS
480 T1=3.14159*(T-TH)/180
490 I=I+1
500 REM initialize star positions
510 X(I)=R*COS(T/57.2958)+150
520 Y(I)=R*SIN(T/57.2958)+100
530 VZ(I)=0:Z(I)=0
540 REM initialize star velocities
545 REM to place them in circular
550 REM orbits about the target galaxy
560 VX(I)=-V*SIN(T1)
570 VY(I)=V*COS(T1)
580 NEXT IT
590 NEXT IR
600 GOSUB 1010
610 REM particle pusher routine
615 FOR K=1 TO NTSPR
620 FOR J=1 TO 1
630 FOR I=1 TO NS
640 REM
650 REM determine the force on a star
655 REM due to the galactic centers
660 REM SF2 below, called the softening factor,
665 REM is used to prevent overflows
670 REM during force calculations
680 REM SF2 is assigned a value above.
685 REM You may experiment with its value
690 REM but it should be kept as small as possible
695 REM to better approximate
700 REM a true 1/r**2 force.
710 REM
720 R1=M1/((X(I)-X1)^2+(Y(I)-Y1)^2+(Z(I)-Z1)^2+SF2)^1.5
730 R2=M2/((X(I)-X2)^2+(Y(I)-Y2)^2+(Z(I)-Z2)^2+SF2)^1.5
740 REM calculate stars x,y,z accelerations
750 AX=R1*(X1-X(I))+R2*(X2-X(I))
760 AY=R1*(Y1-Y(I))+R2*(Y2-Y(I))
770 AZ=R1*(Z1-Z(I))+R2*(Z2-Z(I))
780 REM update star positions and velocities
785 REM using a time centered
790 REM leap-frog algorithm
800 VX(I)=VX(I)+AX
810 VY(I)=VY(I)+AY
820 VZ(I)=VZ(I)+AZ
830 X(I)=X(I)+VX(I)
840 Y(I)=Y(I)+VY(I)
850 Z(I)=Z(I)+VZ(I)
860 NEXT I
870 REM update positions
875 REM and velocities of the galactic centers
880 RR=((X1-X2)^2+(Y1-Y2)^2+(Z1-Z2)^2+SF2)^1.5
890 AX=(X2-X1)/RR:AY=(Y2-Y1)/RR:AZ=(Z2-Z1)/RR
900 VX1=VX1+M2*AX:VY1=VY1+M2*AY:VZ1=VZ1+M2*AZ
910 VX2=VX2-M1*AX:VY2=VY2-M1*AY:VZ2=VZ2-M1*AZ
920 X1=X1+VX1
930 Y1=Y1+VY1:Z1=Z1+VZ1
940 X2=X2+VX2
950 Y2=Y2+VY2:Z2=Z2+VZ2
960 TIME=TIME+1
970 NEXT J
980 GOSUB 1010
990 NEXT K
991 LOCATE 25:PRINT"Continue(1=yes,0=no)";:INPUT "",ANS
992 IF ANS=1 THEN 615
993 GOTO 9999
1000 REM update screen display
1010 CLS
1020 REM calculate center of mass of system
1025 REM for use as center
1030 REM of output display
1040 XC=(M1*X1+M2*X2)/(M1+M2)
1050 YC=(M1*Y1+M2*Y2)/(M1+M2)
1060 ZC=(M1*Z1+M2*Z2)/(M1+M2)
1070 REM set up output display
1080 LINE (0,150)-(300,150)
1090 LINE (150,0)-(150,150)
1100 REM calculate position of galactic centers
1105 REM and display on screen
1110 XX1=(X1-XC):YY1=(Y1-YC):ZZ1=(Z1-ZC)
1120 XX2=(X2-XC):YY2=(Y2-YC):ZZ2=(Z2-ZC)
1130 CIRCLE((XX1+75),(YY1+75)),2,1
1140 CIRCLE((XX1+225),(2*ZZ1+75)),2,2
1150 CIRCLE((XX2+75),(YY2+75)),1,3
1160 CIRCLE((XX2+225),(2*ZZ2+75)),1,3
1170 REM place stars on screen
1180 FOR I=1 TO NS
1190 XP=(X(I)-XC):YP=(Y(I)-YC):ZP=2*(Z(I)-ZC)
1200 PSET((XP+75),(YP+75)),2:PSET((XP+225),(ZP+75)),1
1210 NEXT I
1220 REM print out display headings
1230 LOCATE 21:PRINT TAB(2);
1235 PRINT"      x-y"      x-z"
1240 LOCATE 25:PRINT"Time=";TIME;
1250 RETURN
9999 WIDTH 80:END

```




CONSIDER IT A CHALLENGE: Try reproducing the Antennae Galaxies with GC3D. Are these structures the result of a near pass or a direct collision?

becomes very small).

To avoid this problem, a modified force called the "softened" force is used in the program, in which an extra term we denote as SF2 is added to the gravitational force. (See program lines 720-730.) This has the same effect as if we displaced one of the galaxies vertically above the plane of its orbit by the square root of SF2. In that way, it always passes at least $\sqrt{\text{SF2}}$ from its companion and the magnitude of the forces is thereby limited. This also prevents numerical overload in the computer.

The interaction you get depends on what mass, initial position, and initial velocity you give the intruder (the result goes into program line 380). Of

course, if the intruder has a velocity or position component in the z direction, the test stars will be warped in the z direction. The program solves for the motion of the particles using a time-centered "leapfrog" algorithm. The leapfrog algorithm consists of a two-step process as follows:

$$V_x(T+dT/2) = V_x(T-dT/2) + A_x(T) \times dT \quad (1)$$

and

$$X(T+dT) = X(T) + V_x(T+dT/2) \times dT \quad (2)$$

where X , V_x , and A_x are the x position, velocity, and acceleration, respectively; T is the present value of time, and dT is the time step between updated positions. Identical equations exist for the motion in the y and z

directions. At the beginning of a time step a particle's position, $X(T)$ and its velocity one half of a time step in the past, $V_x(T-dT)$, are known. The particles' accelerations, $A_x(T)$, are calculated based on the positions of the gravitating centers of the target and intruder galaxy (program lines 750-770). Using these values as an estimate of the particle's average acceleration between $T-dT/2$ and $T+dT/2$, updated velocities, $V_x(T+dT/2)$, are calculated using equation (1) (program lines 800-820). Essentially the velocity values leapfrog in time over the position values, hence the algorithm's name. Finally, the newly calculated velocities are used as an estimate of the particle's average velocity between T and $T+dT$ to calculate new positions with equation (2) (program lines 830-850). The position values now leapfrog past the velocity values and we are ready to start the cycle again.

We used this algorithm because, unlike methods of equal or greater accuracy, the particles' accelerations need to be evaluated only once per time step. Because the acceleration calculation is usually the slowest part of an N-body program, use of a time-centered leapfrog makes for a fast calculation cycle and the ability to produce real time movies.

We're interested in your results! If you find leading-arm spirals forming (they won't be around for long in any case) or anything else that intrigues you, please let us know. Send the initial conditions you used, including the number of rings and stars, in care of ASTRONOMY Magazine, Colliding Galaxies Program, 1027 North 7th Street, Milwaukee, WI 53233.

The GC3D program provided can be input by programmers undaunted by numerous keystrokes. However, for those who prefer to skip this chore, ASTRONOMY will, until December 30, provide a free copy of the program to readers who send a blank, formatted computer disk and a self-addressed, stamped disk mailer to the above address. Write "Colliding Galaxies Program" on the package. □

Table 1. Units Used in the Version of GC3D

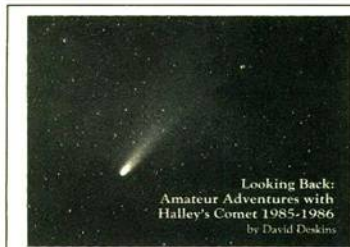
G (universal gravitational constant)	= 1
t (time unit T.U.)	= 1.2 Million Years
d (distance D.U.)	= 500 Parsecs
m (mass unit M.U.)	= 20 Billion Solar Masses

Table 2. Sample Initial Conditions

Result	Mass Fraction	X_0	Y_0	Z_0	VX_0	VY_0	VZ_0
Ring	1.00	7.5	0	35	0	0	-1.0
Bridge	0.25	40	10	10	-1	0	0
Whirlpool	0.25	-30	30	0	0	-0.34	0.34

Michael C. Schroeder is a graduate student in astrophysics at the University of Maine studying disk galaxies. He has a NASA Graduate Student Fellowship. Neil F. Comins is an associate professor of astronomy at the University of Maine. During the time this article was written, Comins was a NASA-American Society for Engineering Education summer faculty fellow at NASA Ames Research Center, Moffett Field, California.

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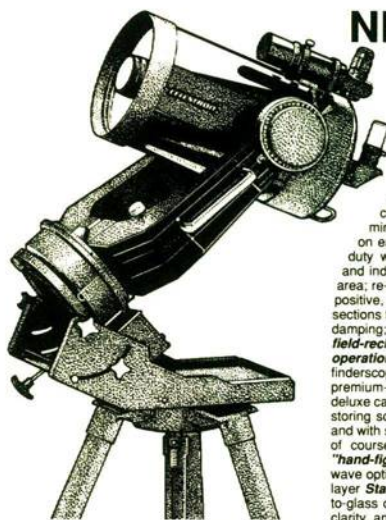
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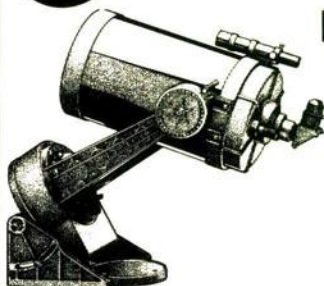
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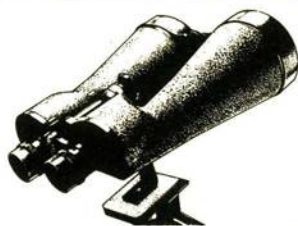
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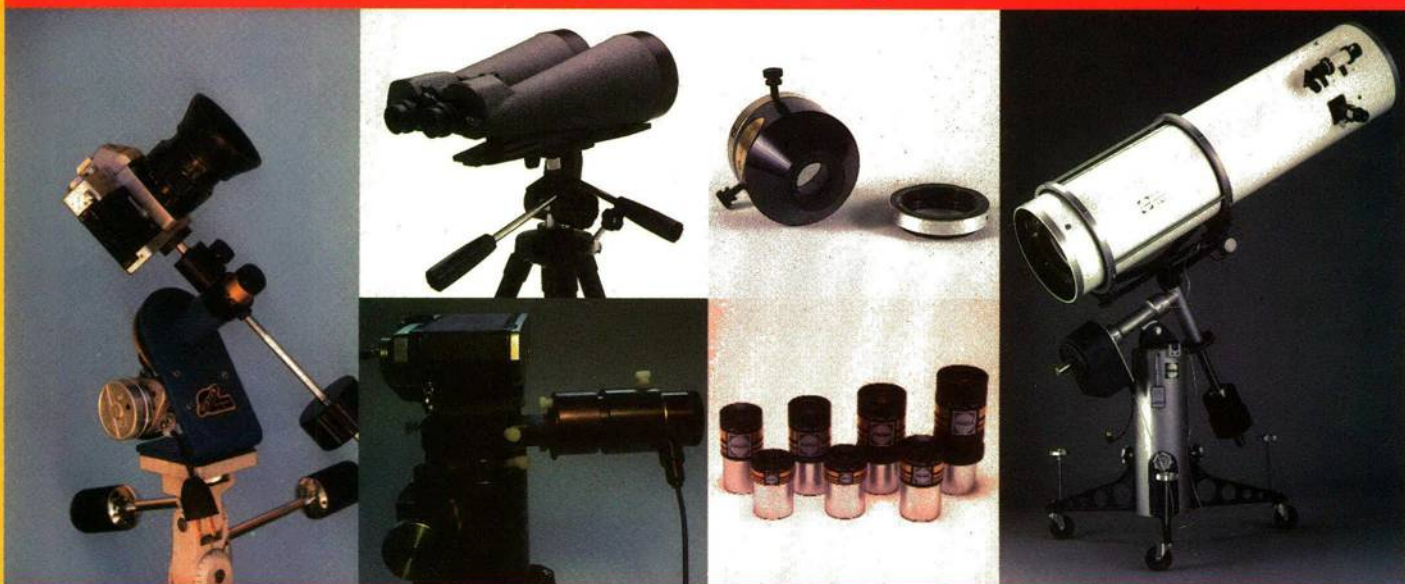
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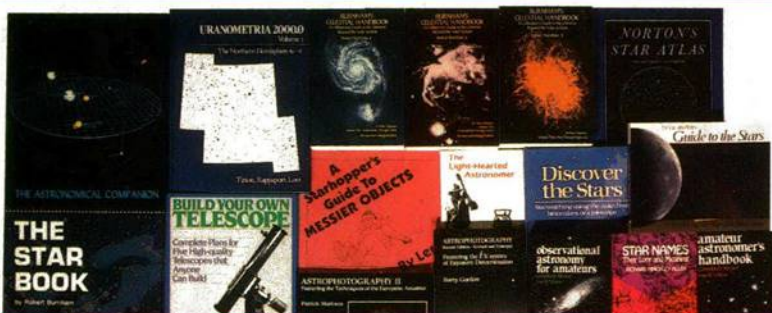
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2080/LX6 (List: \$4,400) **\$1,887.95**
 2120/LX6 (List: \$6,400) **\$2,477.95**

Optional Digital Readout System:

Mod. 9068, for 2080/LX6 (List: \$ 590) **\$ 337.95**
 Mod. 9070, for 2120/LX6 (List: \$ 590) **\$ 337.95**

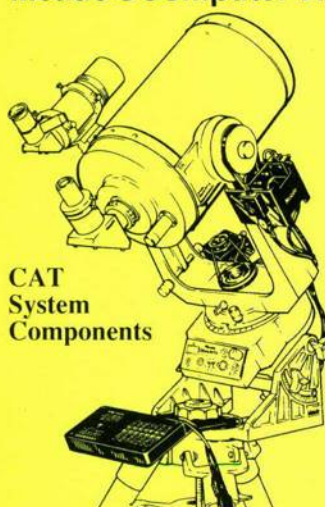
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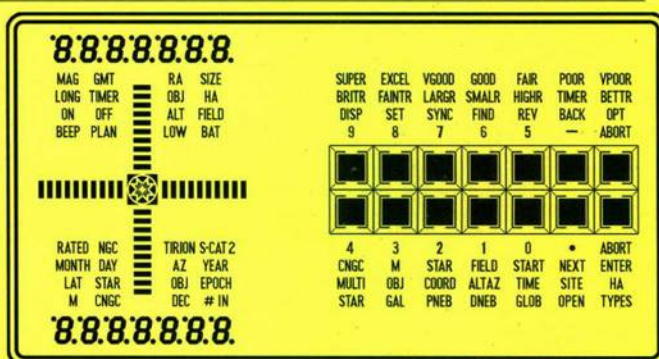
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For the computer-literate, there is also a version of the CAT available with an RS-232C port (the "CAT-COM") for connection to a "PC" compatible personal computer. CAT-COM includes four "demonstration" software subroutines, written in BASIC, to show you how to address and control the CAT from your own computer, as well as the necessary RS-232C interconnect cable. The software is supplied on a 5.25" 360Kb diskette, with backup source-code listings in the instruction manual.

The CAT is available for most fork-mounted Schmidt-Cassegrain telescopes, but has been electronically integrated with the new LX6 series, so that the encoders and the CAT computer plug directly into the drive-base. Consequently, during our introduction of the LX6 series telescopes, we are offering extra savings on packages consisting of an LX6 telescope and one or the other of the CAT systems.



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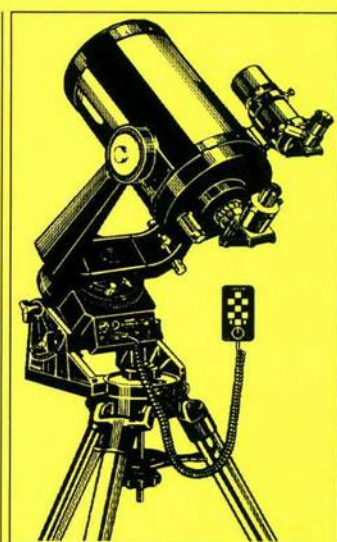
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2080/LX5, MCOG, Wedge, Tripod (as above) .. (List: \$ 3,800) \$ 1,587.95
2120/LX5, MCOG, Wedge, Tripod (as above) .. (List: \$ 5,400) \$ 1,957.95

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Meade's LX3's - Still Going STRONG!

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DSC Sys., for 2080, 2120, C8 or C11		(List: \$ 700)	\$ 377.95
CAT Sys., for 2080, 2120, C8 or C11		(List: \$ 1,990)	\$ 1,187.95
CAT-COM, for 2080, 2120, C8 or C11		(List: \$ 2,290)	\$ 1,362.95
Package Pricing (Electronics System purchased at same time as its telescope):			
DSC Sys., for 2080, 2120, C8 or C11		(List: \$ 700)	\$ 347.95
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PERSEIDS PRODUCE BRIGHT FIREBALLS

Observers called 1988 an excellent year for the Perseids. The Moon was nearly New so it didn't interfere with faint meteors. And the shower, which peaked on August 12, showed as many as forty meteors per hour.

From the Stellafane convention in Springfield, Vermont, George W. Gliba of Greenbelt, Maryland, observed 120 meteors between 1 a.m. and 3 a.m. on the morning of August 12. According to Gliba, who recorded his observations on tape and later statistically analyzed the results, "Ninety-three of the meteors I saw were Perseids. Several other minor showers were going on at the time as well as sporadics, so I had to be careful to include only true Perseids as Perseid observations." At the time the sky had a naked-eye limiting magnitude of approximately 6.3. This translates to overall good sky conditions for central Vermont.

Gliba noted that the average brightness of the Perseids he saw was magnitude 2.5 and that the average color was yellow-white. "About one Perseid in three left a visible train," Gliba said. "The best one I saw resulted from a -3-magnitude meteor and lasted for about thirty seconds."

Tim Printy, president of the Central Florida Astronomical Society, observed the shower from outside Orlando. He found that "the rate this year was about forty per hour. The most I counted was thirty-six between 12:30 and 1:30 a.m. on August 12. However, this rate was rising because I observed nineteen meteors during the last half hour."

Printy believes that "this year's meteors were typical Perseids. Many appeared bluish-white, and I observed an occasional meteor with a greenish tinge. On the whole they were very bright. I calculated that about 50 percent shone at 1st magnitude or brighter and approximately 44 percent left trains. Some of the trains lasted for ten or fifteen seconds.

"I saw two spectacular meteors," Printy said. "One fireball reached magnitude -6 and the other magnitude -8. The magnitude -8 fireball was nearly a point meteor and cast a shadow on the ground. The -6-magnitude meteor left a train that lasted for about twenty seconds. Overall I think this year's shower was better than the one in 1985 and at least as good as the one in 1986."

From the town of Callahan in northern Florida, Karl and Wanda Simmons observed Perseid meteors over a ten-night span. With fellow observers Richard



TWO PERSEIDS FLASHED THROUGH ARIES during the early morning of August 12. Also visible at left are trailed images of Jupiter and the Pleiades star cluster. Mike Walters used a 50mm f/1.4 lens and Fujichrome 400 film.



SPLITTING THE PLANE OF THE GALAXY, a brilliant fireball explodes in Sagittarius at 11:15 p.m. MDT on August 12. The meteor's train remained visible for more than a minute. An airplane trail crosses the meteor trail. Steve Traudt used a 28mm f/2.8 lens, Kodacolor 400 film, and an 8-minute exposure.



A -2-MAGNITUDE PERSEID zips by the constellation Lyra at 1:15 a.m. EDT on August 12. James R. Westlake, Jr., used a 50mm f/1.8 lens and 400 ISO film for the 3-minute exposure.

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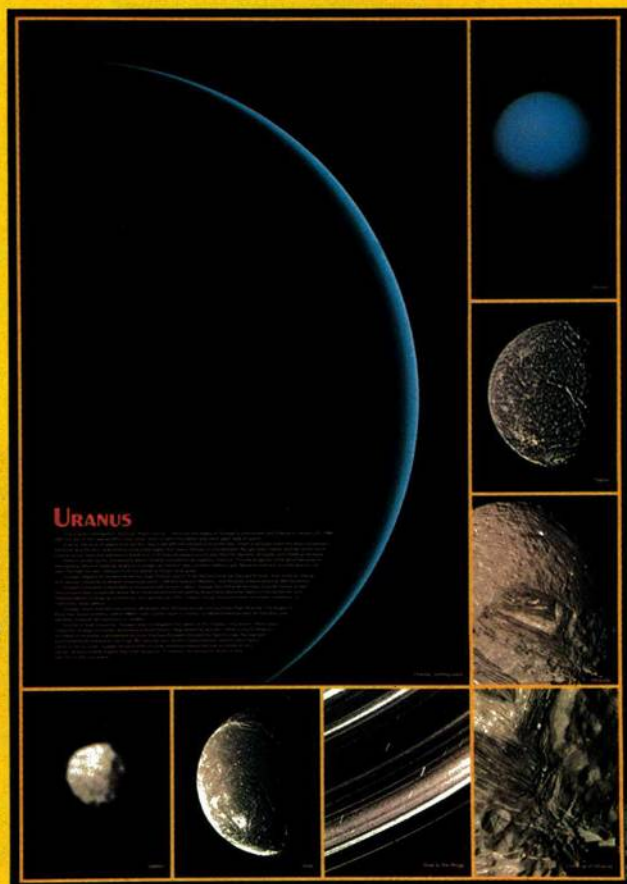
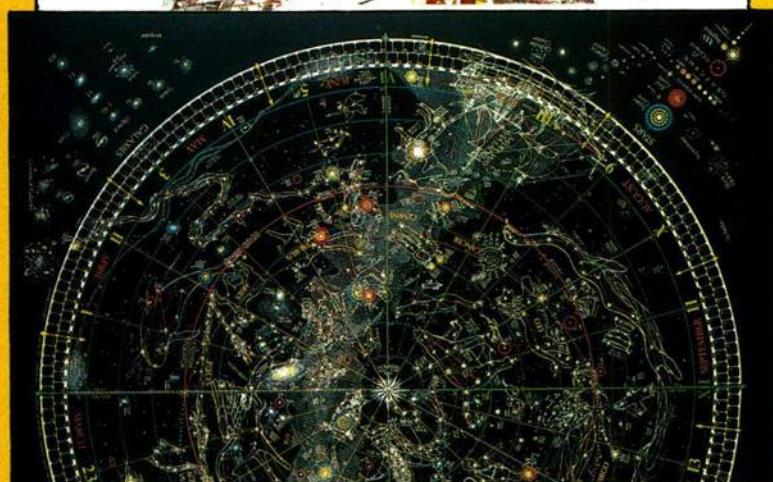
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Sweetsir; John and Becky Kirkwood; and Brian, Stephen, and Wendy Simmons, they counted 1,506 meteors during seventy-five hours of observing and recorded brightness and train information. These calculations help the American Meteor Society, a group of amateur and professional observers, summarize the shower's characteristics.

During the peak hour of Perseid activity Wanda Simmons recorded fifty-two Perseid meteors and fourteen sporadics. During the same period Sweetsir recorded thirty-seven Perseids and twenty-two sporadics. Overall Karl Simmons found that 56 percent of the Perseids observed left trains compared with 11 percent for the sporadics. According to the Simmons' report, the shower peak occurred sometime after 5 a.m. EDT on August 12 because the rate of meteors was still rising when dawn came.

Steve Traudt of Grand Junction, Colorado, observed Perseids for ten nights and was fortunate enough to photograph the brightest meteor he saw. "Capturing this meteor on film was incredible," he said. "The meteor left a train visible for slightly

over one minute.

"I happened to be photographing the area," explained Traudt, "with a 28mm f/2.8 lens tracked on a barn-door mount. I used Kodacolor 400 film and stopped the exposure after the meteor passed through it, about eight minutes into the shot. The photograph only shows about one third of the meteor's path. I don't know what its magnitude was, but this was the brightest and most spectacular meteor I saw."

Not everyone who observed the Perseid shower saw it from the ground. Randy Fromm of La Mesa, California, observed the Perseids from the window of a commercial airliner. "A few days before the shower," Fromm explained, "I was asked to give a technical lecture in Atlanta on Saturday, August 13. Instead of enjoying a night of glorious solitude watching meteors on a mountaintop, I would be flying in the crowded passenger cabin of a commercial aircraft.

"As I boarded the plane to Atlanta at Dallas/Fort Worth, I teased the captain about watching meteors. He said, 'Don't think I'll see any, and besides, we'll be

flyin' through high overcast all the way to Atlanta.' He was right. Lightning illuminated clouds all around us throughout much of the trip. However, during the flight's last thirty minutes I saw twelve meteors through the passenger window. They were bright and seemed to stretch all the way to the ground. After the flight I asked the captain about the shower and he told me he saw a dozen meteors. I left him my August issue of *ASTRONOMY* and, I believe, I created a backyard astronomer!"

COMETS MACHHOLZ AND TEMPEL 2 OBSERVED

As summer 1988 turned to autumn, observers around the globe were busy watching two bright comets. Comet Machholz (1988j) brightened to 6th magnitude by early September but became increasingly difficult to observe as it approached the Sun in the morning sky. In mid-August the comet delighted observers by passing just north of the belt stars in Orion as it continued eastward. Orion's belt, the Orion Nebula, the

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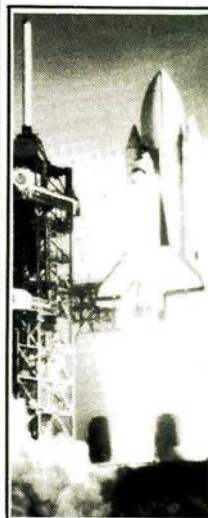
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Editor's Note:

An accidental collector's book: THE GLASS LADY is about the space shuttle Challenger. Published six months before the Challenger explosion, the book is about flight onboard Challenger. When the first printing has been exhausted, the plates will be changed to avoid adding offense to tragedy.

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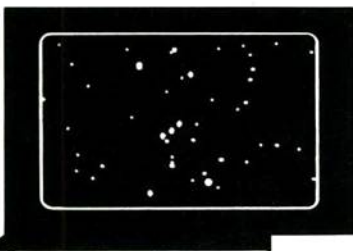
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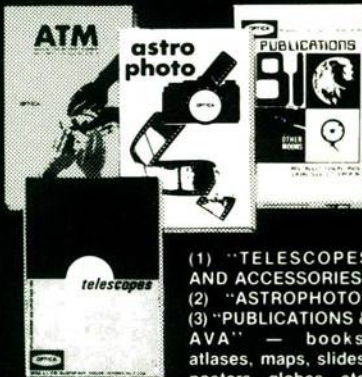
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Horsehead Nebula, and the comet could be photographed in the same frame with a wide-field lens.

On August 25, Terry Lovejoy of Queensland, Australia, observed Comet Machholz with 15x80 binoculars and noted a tail spanning 0.7° . Three days later Lovejoy again observed the comet and saw a 0.3° tail in bright moonlight.

Periodic comet Tempel 2 (1987g) glowed dimly at 12th magnitude in July but rapidly brightened to magnitude 8.3 by the last week of August. Australian Peter Conde watched Comet Tempel 2 from New South Wales and reported, "At 9:25 UT on August 10 I saw the comet for the first time, some $9'$ west of 48 Librae. The comet was rather diffuse, but its coma appeared bright when viewed with averted vision."

Brightness estimates made by Richard Keen in Colorado, John Bortle in New York, and Charles Morris in California confirm the prediction made by Brian Marsden of the International Astronomical Union that Tempel 2 would brighten to 8th magnitude by August. — David J. Eicher □



COMET MACHHOLZ (1988j) shows a slight tail and lies due north of Alnilam, the middle star in Orion's belt, on August 14. Visible at lower left is the Horsehead Nebula. Chris Schur used an 8-inch f/1.5 Schmidt camera, hypered Tech Pan film, and a 5-minute exposure.

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DEBUNKING ASTRONOMICAL UFOS

At some time every astronomer faces the dreaded question: What do you think of UFOs? Replying that UFOs have nothing to do with astronomy is just not true. The main causes of UFO reports are astronomical objects, including stars and planets, meteors, the Moon, and satellites, according to an analysis of 1,300 reports made to the Center for UFO Studies, which investigates UFO sightings.

Astronomy and UFOs are related: if people knew more about astronomy, there would be far fewer UFO sightings. By helping identify sightings, astronomers can do a lot to solve UFO "mysteries."

In the more than twenty years I've been interested in the subject, I have found that there are two main types of UFOs: those that undeniably happened and have a rational solution, and those that can't be backed up with evidence and may not have happened at all.

Evidence for the first type of sighting is often given by highly credible people such as teachers, policemen, and pilots (yes, and astronomers). For instance, former president Jimmy Carter once reported a UFO. The results of the investigation into Carter's story tell us a lot about how wrong UFO witnesses can be.

Carter, a former naval officer trained in celestial navigation and nuclear physics, reported that he and ten other people in the town of Leary, Georgia, watched a

brilliant UFO low on the horizon that appeared to move toward them and away again while changing in brightness, size, and color. Carter estimated the distance of the object at between three hundred and a thousand feet and said at times the object became almost as big and bright as the Full Moon.

This case was investigated by Robert Sheaffer, who describes it in *The UFO Verdict* (Prometheus Books, 1981). Sheaffer found that Carter was nine months off in his recollection of the date. The report was not filed until 1973, four years after the event. But with the correct date established, Sheaffer found that Carter had been looking at brilliant Venus, the biggest UFO culprit of them all.

There are many errors in Carter's report that are typically made by witnesses: the size and brightness are overestimated, the distance is underestimated, and spurious motion is attributed to the object.

Professional pilots have also reported seeing UFOs. An example is quoted by Philip Klass in *UFOs Explained* (Random House, 1974). Pilots aboard a commercial jet flying at 39,000 feet over the United States in 1969 reported being buzzed at a distance of three hundred feet by four objects in formation emitting a blue-green flame. This occurred in daylight, not at night. A military jet flying several miles behind the airliner reported

an approaching squadron of UFOs that suddenly climbed as if to avoid collision.

At the same time as this UFO "encounter" a brilliant daylight fireball broke up in several flaming pieces over the United States, and there seems to be little doubt that this is what the pilots saw, even though the fireball was over one hundred miles away from them. So even experienced pilots can make errors of identification and distance. This doesn't make them bad airmen, simply human.

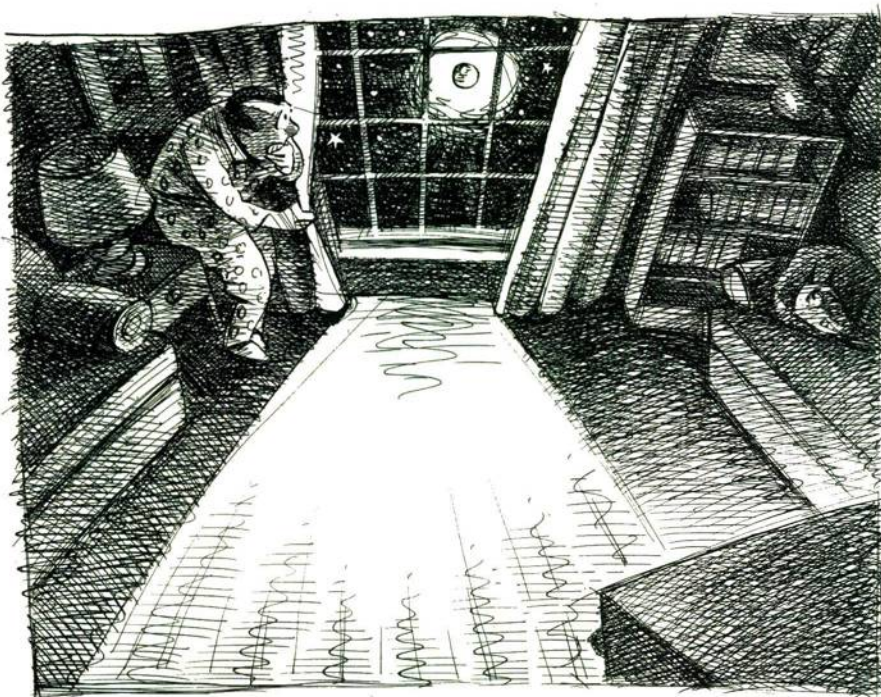
"Chasing" is a familiar phenomenon where an object appears to keep pace with a moving car. Sheaffer describes a one hundred-mile-per-hour police chase of Venus through Ohio and Pennsylvania in 1966. The police never caught it, but the chase did inspire a scene in *Close Encounters of the Third Kind*.

Another example of a "close encounter" with Venus concerns a family in Spain. While driving home one evening, the family reported being chased by a bright light that descended to a height of twenty to twenty-five feet above the car and extended landing gear.

Venus at that time was a brilliant object in the evening sky, but the investigators of this case, who included Willy Smith, professor of physics at Lycoming College in Pennsylvania, rejected Venus as an explanation because it had set at around 9:30 p.m. Greenwich mean time, whereas the Spanish UFO was visible until 10:30. However, Spain keeps time one hour ahead of Greenwich mean time, so the visibility of the UFO exactly matches that of Venus. Hence, even a case endorsed by a professor of physics can have an astronomical explanation.

It is understandable for people to misidentify bright planets and stars — they even misidentify the Moon. In *The UFO Handbook* (Doubleday, 1979) Allan Hendry describes a case in which three witnesses observed a saucer "25 feet in diameter" accompanied by two pulsating lights that hovered over a hospital parking lot for nearly an hour, dimming the parking lot's lights. A humming noise was heard that changed to a loud beeping before the saucer finally shot straight up into the sky. A parakeet owned by one of the witnesses screeched and dogs barked. A woman felt as though she were in a trance.

This has all the hallmarks of a classic UFO case: electromagnetic effects, animal reactions, and physical effects on the witnesses. However, Hendry determined that the witnesses were looking at



the crescent Moon (the "saucer") with Mars and Jupiter next to it (the "pulsating lights"). The dimming of the parking lot lights was caused by intermittent mist that eventually obscured the Moon and the planets. The rest of the report is a product of human imagination. Faced with cases like this, one wonders if it is possible to credit any UFO report.

How can you help weed out obvious astronomical UFOs? Your own knowledge of the sky will help you identify sightings of prominent stars and planets. If in doubt, try asking the witnesses if they saw a bright star as well as the UFO. If they didn't, the conclusion is obvious.

People often give descriptions such as "it seemed to hover for an hour." This is diagnostic of a star or planet. "Flashing colored lights" and "it appeared to be rotating" are characteristic of the way stars such as Sirius appear, twinkling in the south on a frosty winter's night.

Additional information such as "it wasn't there before" or "it appeared to move slowly" or "it dodged around" is still consistent with stars and planets. Many people don't realize that the sky changes in appearance during the year and that planets come and go with greater rapidity than stars. Some witnesses also don't realize that Earth's rotation makes objects in the sky seem to move slowly during the night.

Another more subtle phenomenon is known as the autokinetic effect: natural movements of the eye make a stationary object appear to move irregularly, sometimes zooming up and down or swinging from side to side like a falling leaf.

Unfortunately there is no reference point in the sky to give accurate guides to distance, height, size, speed, or direction of travel, so much of what witnesses report is of little value. All observations made from a moving vehicle are suspect, particularly those made from an aircraft where there is no fixed frame of reference. A planet millions of miles away, an aircraft several thousand feet away, and a flashlight a few dozen yards away all appear about the same size and brightness at night.

Your astronomical knowledge can help explain UFO sightings. There are so many sightings that no one can be expected to know the answer to all cases you hear about, but the above examples should give pause to all but the most determined believers. If someone asks whether you've seen a UFO yourself, remember Arthur C. Clarke's riposte: "If you've never seen a UFO, you're not very observant. And when you've seen as many as I have, you won't believe in them." — Ian Ridpath □



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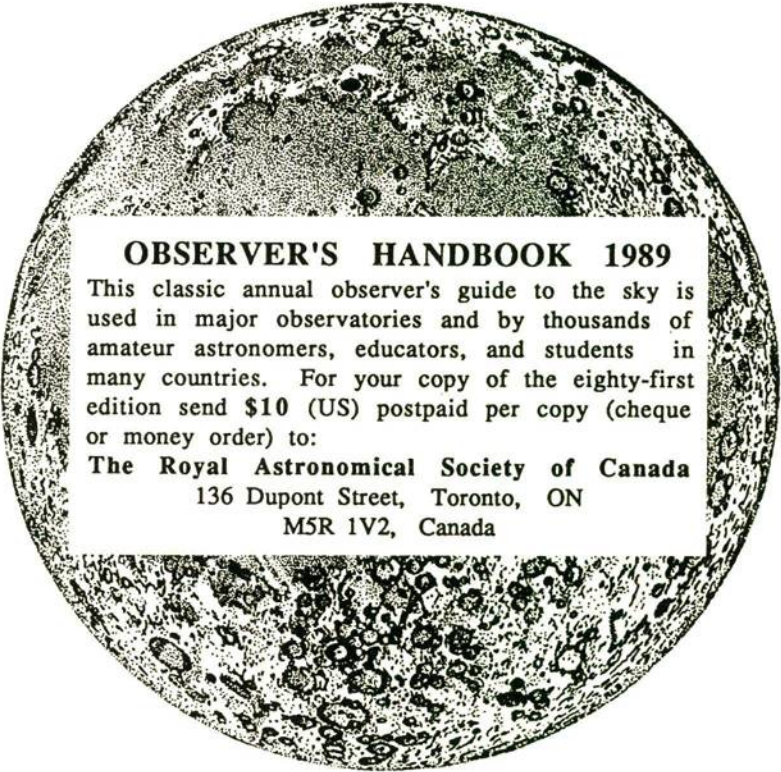
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*Astronomy Magazine, 10/84



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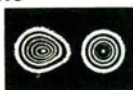
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Astronomy Books

THE REDSHIFT-DISTANCE CONTROVERSY

Quasars, Redshifts, and Controversies by Halton Arp, (Interstellar Media, 1987), ISBN 0-941325-00-8, hardcover, 198 pages, \$19.95

Many years ago I had the pleasure of introducing "Chip" Arp to the game of tennis and, I believe, to extragalactic spectroscopy. His latest book indicates how he has pursued at least one of these disciplines.

The topic of *Quasars, Redshifts, and Controversies* is extragalactic spectroscopy, a field in which Arp holds unorthodox opinions. Some of these opinions prevent many astronomers from taking him seriously. Arp complains frequently of the reception accorded his opinions, in sometimes strong language, leveling accusations of prejudice and even outright dishonesty.

Anyone who has ever embraced unusual scientific opinions and tried to have them published in science journals has encountered the referee who knows better than the author or advises rejection of the paper on the grounds that the opinions are wrong. Arp has met such obstacles, but his book is a vehicle that defies them, and by its publication he certainly has his day in court.

Essentially Arp believes that the redshifts of the spectra of quasars and even galaxies cannot be interpreted solely as the result of Doppler effects caused by recession velocities. The Doppler effect, as it relates to electromagnetic radiation, is simply the change in the apparent frequency of the radiation emitted by a celestial object as a result of the relative motion of that object and the observer. The wavelengths of receding galaxies and quasars are longer — redshifted — than they would be if these bodies were at rest. (They would be blueshifted if they were approaching.)

Furthermore, the faster they recede, the greater their redshifts. Because the cosmic expansion rate increases with distance, the magnitude of the redshift is considered a reliable distance indicator. This relationship results in a neat little maxim: the greater the redshift, the greater the distance.

This redshift-distance relationship is one of the premises of modern astronomy, and it is exactly what Arp is attacking. On many occasions he has drawn attention to the close proximity on the sky of high-redshift quasars and low-redshift galaxies, which are often peculiar galaxies. Arp contends in chapter two that there are more quasars close to cer-

tain galaxies than could be expected by chance. In some cases he maintains that there are physical connections between galaxies and quasars, as evidenced by the appearance of luminous bridges or ejecta from very active galaxies. The most famous of these is the apparent connection between NGC 4319, which has a redshift of 0.005, and the quasar Markarian 205, which has a redshift of 0.072.

Some of the cases he cites look plausible enough, but his opponents will have none of this, declaring that no more quasars are found near galaxies than can be accounted for by sheer chance. One wonders whether such chance concentra-



QUASARS, REDSHIFTS AND CONTROVERSIES

by Halton Arp

tions that are not associated with galaxies exist.

Of course, it is not unusual to find galaxies displaying violent ejections of material. That these ejections might be composed of extraordinary stuff, as Arp would have us believe, is certainly plausible. On the other hand, it seems less likely that something extraordinary might lie on an apparently normal spiral arm, as Arp suggests is the case with NGC 1073.

Nevertheless, if just one of these connections can be proved real, then the quasar redshifts cannot be due entirely to the expansion of the universe. The implications of such a revelation would be far-reaching. After all, the distances of galaxies and the general expansion of the universe have been based on this assumption. And if not all of a redshift is

due to recession velocity, how does one partition the observed value? According to Arp, the intrinsic part of the redshift is what is left over after some value of the Hubble constant has been applied. (Explanations for deviations in the case of nearby galaxies are mixed up with that other hot controversy — the value of the Hubble constant.)

Arp develops his ideas until they conflict with most aspects of modern cosmology, and it seems unlikely that he will convince many readers who support those principles. However, he performs a service by pointing out nagging discrepancies that have not been adequately explained, such as the occurrence of maverick redshift galaxies in groups that certainly seem to be interacting.

Arp hammers on a door seemingly firmly closed by what he calls the astronomical establishment — those colleagues who only a few decades ago were espousing their own revolutionary ideas, which seemed almost equally unlikely at the time. He mentions, as a point of criticism, the remark by a senior colleague that someone other than Arp will have to finally make his case. In fact, this seems a counsel of wisdom. Some day the heat will die down and others will be alert to the inconsistencies in current ideas. The history of scientific progress demonstrates that justice does not always prevail within the lifetimes of proponents of the unorthodox. But eventually truth does. — *David S. Evans, University of Texas*

NATIVE AMERICAN MYTHS OF THE SKY

They Dance in the Sky: Native American Star Myths by Jean Guard Monroe and Ray A. Williamson, (Houghton Mifflin Company, 1987), ISBN 0-395-39970-X, paperback, 130 pages, \$12.95.

For many of us who love the night sky, memories of our first encounter with the stars revolve around stories we heard as children. A parent, older sibling, or youth group leader pointed out the Big Bear spiraling around the pole star or Orion chasing his prey across the sky. As we grew older, we became "educated" about the stars and perhaps they lost some of their mystery and romance. Jean Guard Monroe and Ray Williamson bring back the mystery for us with the star stories of the Native Americans.

Williamson's previous book, *Living the Sky* (Houghton Mifflin, 1984, reviewed in the July 1986 issue of *ASTRONOMY*), provided a much needed introduction for the general reader to Native American

astronomy and the science of archaeoastronomy. This recent contribution, although not directly a sequel, is a fine companion to *Living the Sky*. Monroe and Williamson write for a general audience. In fact, one might even consider this a children's book (for children of all ages!), intended to be read aloud. The authors gleaned the stories mainly from unpublished scholarly books and notes of researchers. They hope "to convey some of the excitement of these myths and to put them in the context of the world from which they came, a world that for many tribes is lost." They succeeded.

The first two chapters focus on the Pleiades and the Big Dipper. Usually the storytellers attempt to explain the origin of a constellation. A common theme is the flight to the sky of humans, often children, whom we now see as the sparkling stars. In some cases, a manifestation of evil (an old woman, an old man, or a coyote) lured the children, or they danced themselves into the sky. The seven stars (as seen by most) in the Pleiades represent south, west, north, east, up, down, and center, the total number of possible directions. Concerning the Big Bear, the authors note that European explorers must have been astonished that the bear designation was common to both cultures.

The remaining six chapters divide the myths into regional groups: "Myths from the Southwest," "Legends of the Pawnee," "Legends of the Plains Indians," "Stories of the California Indians," "Stories from the Northwest Coast," and "Tales from the Southeast." The cultural and astronomical background of the particular region or group sets the stage for the stories recounted. At the end of each chapter Monroe and Williamson supply a valuable reference by listing the Western equivalent for Indian names of stars and constellations. These names show an insight into the nature and beauty of the stars. The Omaha tribe called Polaris the "Star That Does Not Walk Around." Try to guess the western name for these: "Revolving Female" (Navajo), "Boy and Girl" (Klamath), and "Where the Dog Ran" (Cherokee).

A glossary at the end of the book provides a helpful listing of stars, constellations, and Native American names. "Suggested Readings" furnish the general reader with a catalog of books on Native American storytelling, and a bibliography gives the scholarly sources for much of the material in the book.

When you read this book, read the stories aloud. Originally they were part of a rich oral tradition and thus beg to be spoken. Read them to children. Read

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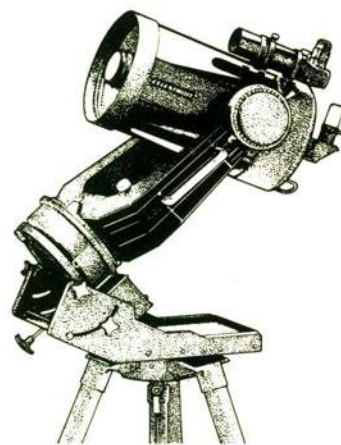
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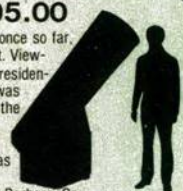
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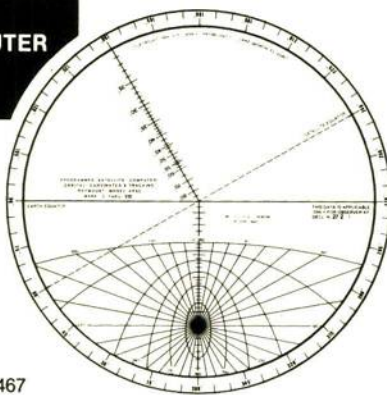
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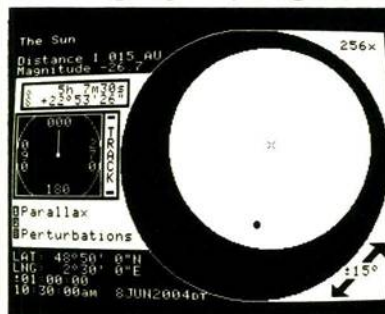
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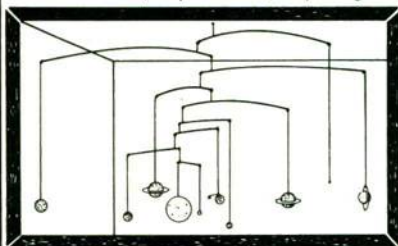
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While it would be very unwise (to say the least) to drive out to the site wearing them, the goggles can hasten your eyes' adjustment to dark conditions if you put them on before it becomes fully dark. Perhaps more importantly, they will preserve a hard-won dark adaptation if you find it necessary to go into a regularly lit room while you're observing.

Astrogoggles won't be much use to planetary observers, whose targets are mainly bright, but they will be invaluable to any deep-sky observer. A good product whose time has come. — Robert Burnham

Moon posters, (Celestial Arts, P.O. Box 7327, Berkeley, CA 94707), \$7.95 each.

Celestial Arts has produced two posters of the Moon: one shows Last Quarter, the other is a photomontage "Full Moon" made by joining a First Quarter photo to one from Last Quarter. The Last Quarter poster measures 27 inches by 36; the

"Full Moon" is 27 inches square. The photos are satisfyingly detailed and contrasty, and both appear to have a lightly varnished surface.

Each poster comes with a small leaflet that describes the Moon's phases, identifies the main surface features, and lists the partial and total lunar eclipses through 1999. Across the top of each poster runs the word "Moon" in several languages, while the poster's lower edge carries the name of the publisher and printer and the source of the photo.

SLIDES

Stones, Wind, and Ice by Nadine G. Barlow and Virgil L. Sharpton, (Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058-4399; (713) 486-2143; 1988), 30 slides and 11-page booklet, \$13.

Stones, Wind, and Ice sounds like it might be a tour of terrestrial landscapes above the timberline or in the Arctic regions; in fact, it presents an assortment of Martian impact craters. (Two exceptions: one photo each of Phobos and Deimos.) The thirty slides are mostly



SINUOUS RIDGES surround Argyre crater on Mars, from the *Stones, Wind, and Ice* slide set.

black and white; color is limited to two graphs, a Viking lander scenic shot, and two whole-planet geological maps.

Each photo is numbered and labeled so finding the description in the booklet that corresponds to it is easy. The text describes the photo, puts it in the context of Martian geology as a whole, and tells you the mission frame number. The booklet concludes with a glossary and a list of readings.

The photos have good picture value: their contrast is crisp but not soot-and-whitewash. Unfortunately, nearly all of them include distance scales and many have arrows pointing out the feature of interest. While the didactic approach makes the set valuable to educators, I wish the compilers had not been so insistent that we see only what they want us to see. In other words, if they hadn't treated the photos as data and instead let us explore them on our own with the help of the text, the set might have a wider appeal. — Robert Burnham

Volcanoes on Mars by James R. Zimbelman, (Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058-4399; (713) 486-2143; 1988), 20 slides and 11-page booklet, \$10.

The twenty slides in this set focus on Martian volcanic landforms. All are in



LAVA FLOWS on Olympus Mons, from the *Volcanoes on Mars* slide set.

black and white (except for the first, which shows Earth and Mars in relative scale, and the third, which shows the Tharsis Mountains), and all are taken from *Viking* pictures.

Each slide is labeled with a number and the name of the main feature visible. This keys directly into the booklet's text, which gives a description of the feature and its relation to others nearby. In addition, the text identifies the picture frame number from the mission. The booklet concludes with a short glossary of geological terms and a list of references for further reading.

As with *Stones, Wind, and Ice* (above), this set treats the photos as "facts" to the detriment of pictorial values because distance scales and indicator arrows are included. If you're a teacher, you won't mind, but if you're a space buff, you may find the intrusions detract somewhat from the set's value. — Robert Burnham

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Pacific Planetarium Association Fall Conference, Santa Rosa, California. Contact: Ron Oriti, Santa Rosa Junior College Planetarium, 1501 Mendocino Avenue, Santa Rosa, CA 95401.

November 16

Centennial Celebration and Rittenhouse Medal Award Ceremony, Franklin Institute, Philadelphia, Pennsylvania. Sponsored by the Rittenhouse Astronomical Society. The award will be given to Eugene and Carolyn Shoemaker. Contact: Rittenhouse Astronomical Society, Box 24716, Philadelphia, PA 19111.

January 8-12, 1989

173rd Meeting of the American Astronomical Society, Boston, Massachusetts. Professional meeting hosted by the Massachusetts Institute of Technology. Contact: American Astronomical Society, 2000 Florida Avenue, N.W., Suite 300, Washington, DC 20009.

February 2-5

5th Annual Winter Star Party, Florida

Keys, Florida. Sponsored by the Southern Cross Astronomical Society. Contact: Tippy D'Auria, 1051 N.W. 145th Street, Miami, FL 33168. Phone: (305) 685-6001.

May 28-June 4

Texas Star Party, Prude Ranch, Fort Davis, Texas. Contact: T.S.P. Registrar, Department "A," P.O. Box 386, Wylie, TX 75098.

June 21-25

Centennial Meeting of the Astronomical Society of the Pacific, University of California at Berkeley. Contact: Berkeley Meeting Information, A.S.P., 390 Ashton Avenue, San Francisco, CA 94112.

Please submit announcements at least four months before the date of the meeting or event.

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Readings and Resources

Pulsars (page 22)

The Invisible Universe Revealed: The Story of Radio Astronomy by Gerrit L. Verschuur, (Springer-Verlag, 1987). The book contains a comprehensive chapter on pulsars.

"The Oldest Pulsars in the Universe" by Jacob Shaham, *Scientific American*, February 1987. A semitechnical article on pulsar physics.

Voyager 2 (page 34)

"Aiming for Neptune" by Charles E. Kohlhase, *ASTRONOMY*, November 1987. A Voyager mission designer describes the planning process behind the August 1989 Neptune encounter.

Uranus and Neptune by Eric Burgess, (Columbia University Press, 1988). A review of the scientific findings of the Voyager Grand Tour with an emphasis on the Uranus flyby.

Otherworldly Visions (page 44)

International Association of Astronomical Artists, P.O. Box 37197, Tucson, AZ 85740.

Confusion Limit (page 56)

The Big Bang by Joseph Silk, (W. H. Freeman and Company, 1988). Chapter ten contains a detailed treatment of the origin and evolution of galaxies.

Mars (page 76)

The Association of Lunar and Planetary Observers, an organization of amateurs and professionals, is collecting Mars observations. Contact Jeff Beish, ALPO Mars Recorder, 9460 Toni Drive, Miami, FL 33157.

Guide to Mars by Patrick Moore, (W. W. Norton, 1977). A general guide

to observing Martian features and understanding the Red Planet.

Mars by Patrick Moore and Charles A. Cross, (Crown Publishers, 1973). Contains large-scale duotone maps of the Martian surface.

Low-Angle Observing (page 82)

The Nature of Light and Color in the Open Air by M. Minnaert, (Dover Publications, 1954). An introduction to the physics of light and color in nature.

Rainbows, Halos, and Glories by Robert Greenler, (Cambridge University Press, 1980). A study of scattering, diffraction, refraction, and the optical effects they produce.

Sunsets, Twilights, and Evening Skies by Aden and Marjorie Meinel, (Cambridge University Press, 1983). An introductory physics approach to the green flash, sunset phenomena, zodiacal light, noctilucent clouds, and other light and color effects.

Galactic Collisions (page 90)

"Advanced Computing for Science" by Piet Hut and Gerald Jay Sussman, *Scientific American*, October 1987. Describes the latest in computer modeling in science and features recent galaxy-collision simulations.

A Catalogue of Southern Peculiar Galaxies and Associations by Halton C. Arp and Barry F. Madore, (Cambridge University Press, 1987). A catalog of colliding and interacting galaxies.

"Violent Tides between Galaxies" by Alar and Juri Toomre, *Scientific American*, December 1973. One of the early popular-level articles on what astronomers were learning from computer models of galaxy collisions.

CREDITS

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The new frontiers for space science into the next century and the final preparations for 1989's *Magellan* and *Galileo* missions to Venus and Jupiter.

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Your comprehensive guide to all the year's astronomical events.

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You don't have to live fifty miles from city lights to shoot great astrophotos.

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HEALDSBURG, CA 95448

Oops!

Despite our efforts to be all-inclusive in compiling the ASTRONOMY Equipment Directory (Oct. '88 issue) we inadvertently omitted several telescope suppliers who responded to our questionnaire. All are manufacturers/importers, retailers and mail order dealers of a wide variety of astronomy equipment, from telescopes and observing aides to astrophotography supplies and software.

They are as follows:

Efstonscience, Inc.
3350 Dufferin Street
Toronto, ONT MGA 3A4
(416) 787-4581

Lewis-Michaels Engineering
48 Delemere Blvd.
Fairport, NY 14450-0248
(716) 425-3470

Texas Nautical Repair Co.
2129 Westheimer
Houston, TX 77098
(713) 529-3551 or (713) 529-8480

1989 Calendars & Charts



Visa / MasterCard / COD orders call:
1-800-235-3783
Quantity Discounts Available

- Moonlight 1989 \$8.00
- Graphic Timetable of the Heavens 1989 \$8.00
- Astronomical Calendar 1989 by Guy Ottewill \$12.00

(Prices include surface shipping via UPS or USPS in Cont. U.S.)
Shipments to Virginia add 4.5% sales tax.

Celestial Products, Inc.
10 W. Washington St., Middleburg, VA 22117

CANADA



Suppliers of:
Bausch & Lomb
Celestron
Lumicon
Meade
Optec
TeleVue
Hypered films & More

Catalog — \$4.00

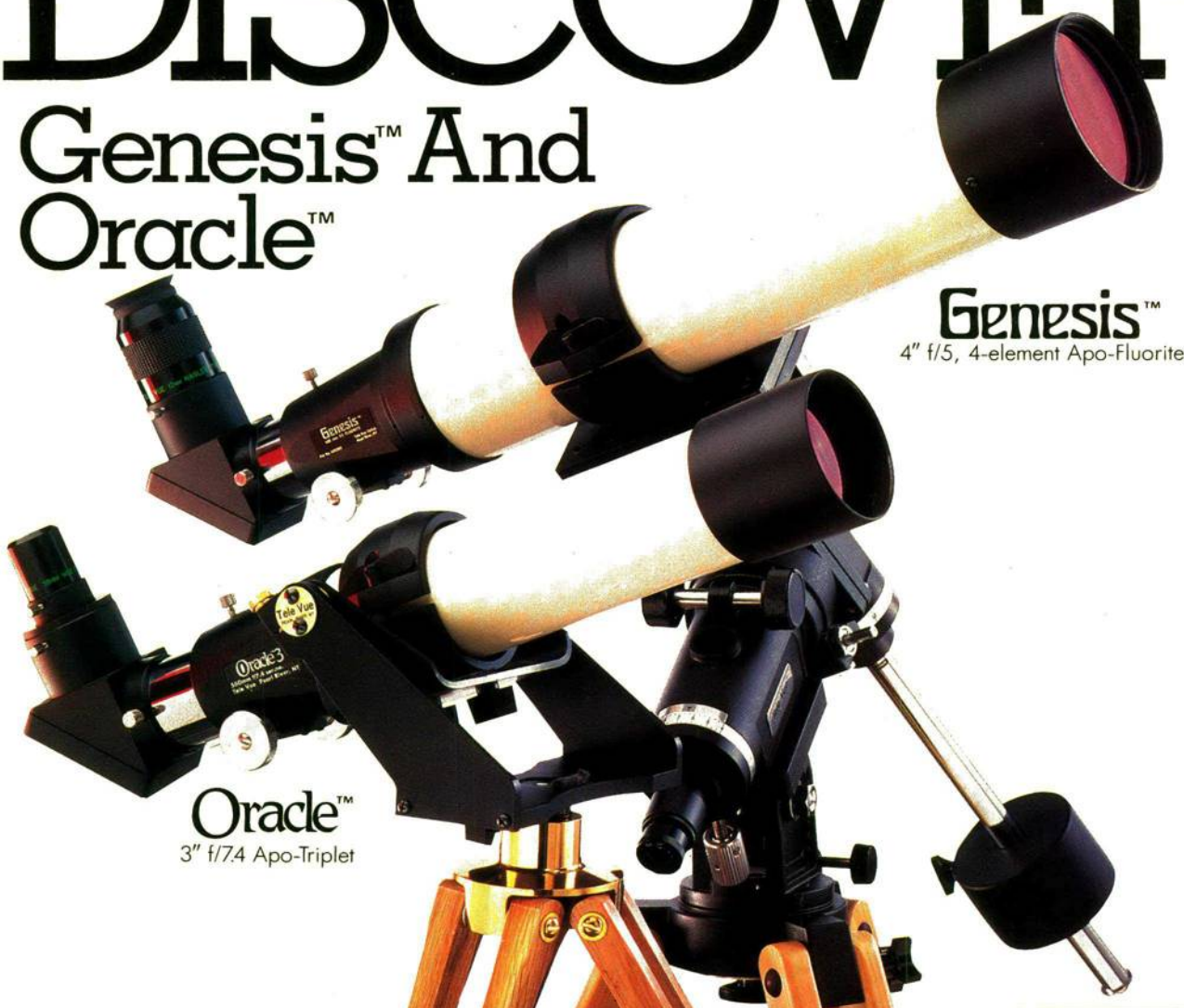
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(403) 255-7633

DISCOVER

Genesis™ And Oracle™



Genesis™

4" f/5, 4-element Apo-Fluorite

Oracle™

3" f/7.4 Apo-Triplet

Tele Vue apochromatic refractors deliver pinpoint star images across a vast 5° field at 10x to over 250x. The greatest magnification range in high performance refractors. Superb color-correction, contrast and resolution make them ideal for studying Mars at close approach, double stars, nebulae, and Milky Way star clouds.

Discover what owners have already found: Oracle and Genesis telescopes are designed for serious fun.



Genesis photo courtesy Jim Riffle

Genesis

"I wanted the best refractor ... it is fantastic!"

—Robert Godfrey, NY

"Due to the Genesis' remarkable performance as a wide-field RFT, guide scope and astrograph, it is now being included as standard equipment on our 12" f/5 Astromak."

—Jim Riffle, Pres.
ASTRO WORKS

Oracle

"I was fooled by the size of this scope. I've owned Newtonians and Cassegrains before, and I can't believe this 'little' scope delivers such perfect images."

—John Ossowski, NY

"The resolution and contrast are great. I'm very happy with this well crafted instrument."

—Bob Sella, FL

"A beautiful instrument; exquisite quality."

—Norman Tandy, NH

Extraordinary Value

Genesis and Oracle come with: deluxe case, screw-on metal cover and dew shield, 2" rack and pinion focuser with lock screw, 2" mirror-type star diagonal, 1¼" adaptor, adjustable mounting ring and a 26mm Plössl.

Whether you're seeking superior sharpness, a more manageable companion to larger instruments, or the finest first telescope, Genesis and Oracle offer no-compromise choices! Send \$1 for complete literature.

Tele Vue™

20 Dexter Plaza, Pearl River, NY 10965
(914) 735-4044

BETTER FROM THE INSIDE OUT

Celestron proudly introduces the ULTIMA 8—the finest 8" Schmidt-Cassegrain telescope in the world.

The design features incorporated in the Ultima 8 offer the beginner and the serious amateur ease-of-use along with sophisticated innovations not available in other 8" scopes.

UNSURPASSED OPTICAL EXCELLENCE

►Ultima's properly baffled 8" aperture, 2032mm focal length, f/10 Schmidt-Cassegrain optical system is simply the best you can buy.

►Starbright® optical coatings group produces the brightest image available on any 8" Schmidt-Cassegrain scope.

MECHANICAL/STRUCTURAL STABILITY

►New larger, more rigid castings for fork tines, drive base, polar shaft and rear cell make Ultima 8 incredibly stable.

►Improved tripod with rubber coated legs and heavy duty wedge for rock solid viewing and astrophotography.

CORDLESS ELECTRONIC DRIVE

►Quartz-Locked accurate and easy-to-use electronic drive system is *totally cordless*—no separate power requirements or myriad of wires to contend with.

►Base includes built-in, sealed, rechargeable lead acid batteries for a full night's operation on a single charge. Drive corrector elements for advanced astrophotography are included—add only a simple hand controller.

ULTRA-ACCURATE DRIVE GEAR SYSTEM

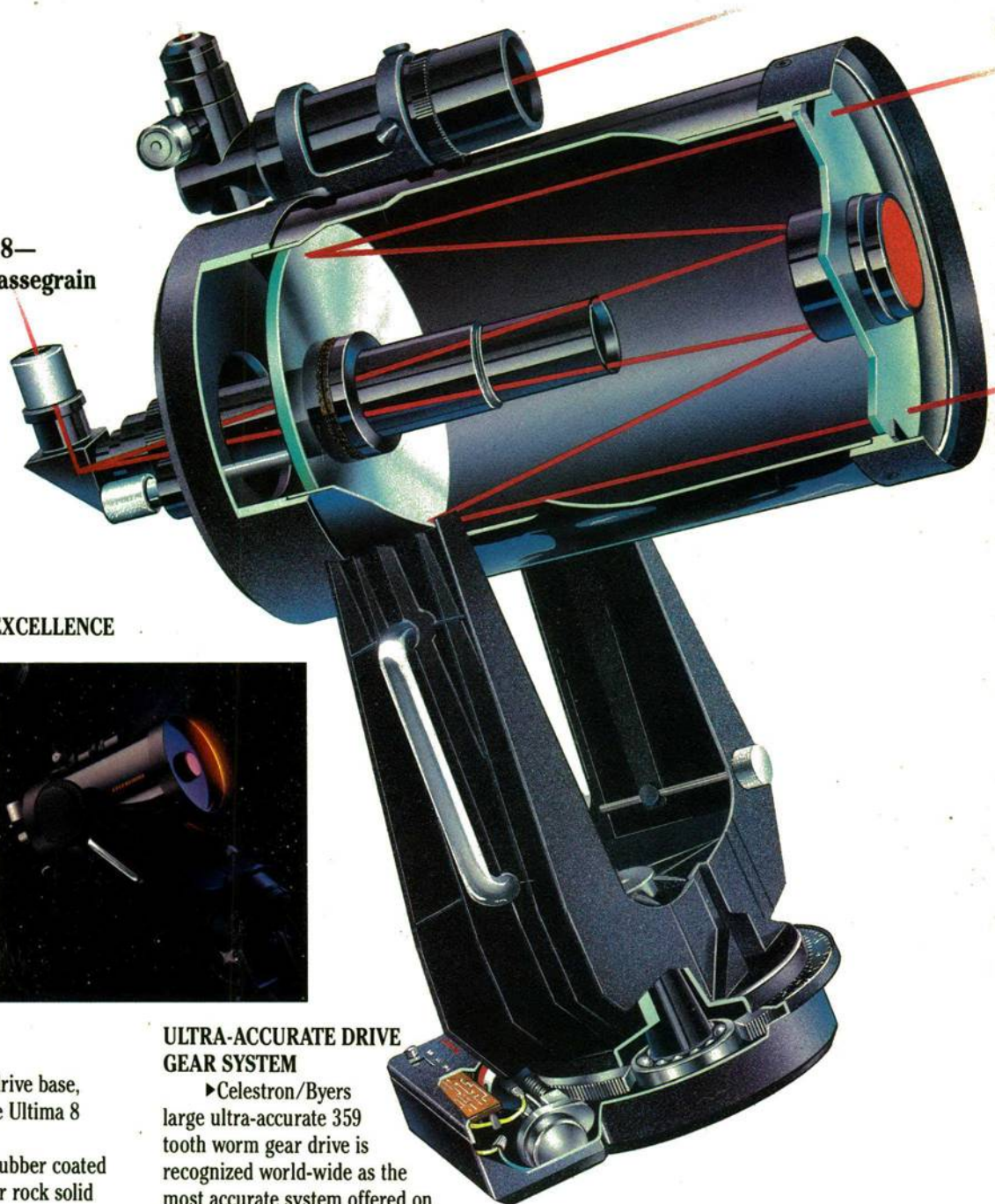
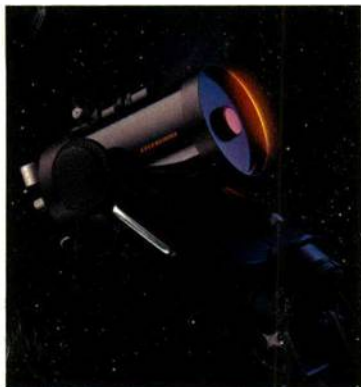
►Celestron/Byers large ultra-accurate 359 tooth worm gear drive is recognized world-wide as the most accurate system offered on any commercial fork-mounted telescope.

USER-FRIENDLY OPERATION

►Convenient carrying handles on the forks and rear cell for safe, easy handling.
►Deluxe foam-fitted carrying case.
►Covered by Celestron's limited lifetime warranty.

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►Wide angle, bright-image 30mm Multi-Coated 1¼" Plossl eyepiece and high power 7mm Orthoscopic ocular.



See the Ultima 8 at your Celestron dealer today.



Call 1-800-421-1526 for a free color brochure for details on the extensive array of optional accessories available as well as more information on the features of the Ultima 8.



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